PRACTICE OF SURGERY

Stone Surgery

MICHAEL MARBERGER
JOHN M. FITZPATRICK
ALAN D. JENKINS
CHARLES Y. C. PAK

Churchill Livingstone

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MICHAEL MARBERGER MD
Professor and Chairman,
Department of Urology,
University of Vienna Medical School,
Vienna, Austria

JOHN M. FITZPATRICK MCh FRCSI
Professor of Surgery,
Mater Misericordiae Hospital and University College,
Dublin, Ireland

ALAN D. JENKINS MD
Associate Professor of Urology,
University of Virginia School of Medicine,
Charlottesville, Virginia, USA

CHARLES Y. C. PAK MD
Professor of Internal Medicine,
Center for Mineral Metabolism and Clinical Research,
The University of Texas Southwestern Medical Center,
Dallas, Texas, USA

ILLUSTRATIONS BY
PHILIP WILSON FMAA AIMI

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Chapter 1

Introduction

M Marberger, J M Fitzpatrick, A D Jenkins, C Y C Pak

The changes which have taken place in the management of stones within the last decade have been truly remarkable. Whereas in the past the urologist was faced with only two options, to operate or not to operate, the number of therapeutic choices at the present time has mushroomed. With the development of newer endourological instruments, the entire urinary tract can now be visualized either percutaneously or transurethrally. The effects of all these changes have ensured that the patient can be managed in a less invasive manner, with a lower morbidity and an earlier return to his family and working environment.

It has been difficult to keep pace with the continuous evolution in the management of urinary calculi over the past few years. In the past, open stone surgery was almost invariably the rule for larger renal and ureteric calculi, whereas now the urologist in many cases looks on it as a form of defeat. This has led in some cases to calculi being managed by less invasive means when operative methods might well have been introduced at an earlier stage. Other changes were taking place at the same time as advances in endourology. The increasing use of extracorporeal shock wave lithotripsy brought the management of stones to the ultimate method: non-invasion.

The continuous evolution of treatment modalities meant that writing a book about urinary calculi was a risky business, because it would have been almost out of date by the time it was published. We feel that this book is timely, because it certainly seems that this continuous evolution has slowed up. It is unlikely that there will be any significant advances in the management of urinary calculi within the foreseeable future, because every effort at the moment is being made towards improving the technology currently available, as well as attempting to decrease its cost.

The aim of this book is to present to the reader a comprehensive view of urinary calculi. There is a detailed discussion of the causes and composition of calculi, as well as the investigations required for the diagnosis. The role of medical management of urinary calculi is also looked at and its place in the overall management of this condition is described. Open stone surgery is reviewed in detail, with emphasis being laid on the various types of conservative incisions through the renal parenchyma. In addition, renal preservation for in situ ischaemic renal surgery is given special attention.

The changes which took place and the progression from open stone surgery to percutaneous removal of renal calculi are described. Once this concept was introduced, the techniques and instruments for removing calculi and disintegrating them using various forms of energy, were a welcome by-product. The final endoscopic advance was the introduction of the rigid and then the flexible ureteroscope. This has ensured that the previously frequently performed operation of ureterolithotomy is now a rarity.

As everyone knows, while these advances in endoscopic removal of urinary calculi were being made, the ultimate in non-invasive surgery was being developed. Extracorporeal shock wave lithotripsy can now be applied to virtually every urinary calculus. In this book, its place in the management of such calculi is described, in addition to the adjunctive use of endoscopic procedures.

In many instances, the calculus which requires treatment is complicated by other extraneous factors. For example, the stone may lie in a horseshoe kidney with an associated pelviureteric junction obstruction; calculi in calyceal diverticula have often posed the question, to treat or not to treat? In addition to these, many other complicated stone problems have been confronted in this book, and advice given to readers as to how best they can be managed. So important do we consider the practical aspects of stone treatment that 2 of the authors discuss a total of 21 cases and present their differing views on their management. The aim of that particular Chapter is to stimulate the reader into formulating his own ideas on the management of the cases in question, based on their reading of other Chapters in this book.

We present what we feel is a comprehensive review of the management of urinary calculi. It is aimed, not only at qualified and practising urologists, but also at residents in training. It is hoped that it will stimulate thought into what is a complicated subject. It is essential, therefore, that the basic principles which are clearly described in this book, be grasped as early as possible by those who wish to practice urology and advance it as a science.

Chapter 2

Indication, timing and preoperative evaluation

M Marberger

6 Stone surgery

INDICATION

The spontaneous dissolution of urinary calculi has only been observed under exceptional circumstances, e.g. immobilization stones in children (Pyrah 1979). Whereas uric acid stones are readily dissolved by oral alkalinization of urine, peroral chemolysis of cystine stones fails quite frequently. Struvite stones will only disappear in the rare case of urinary infection and bacterial urease activity being eliminated (Griffith et al 1978). Any other type of renal stone can only be cured by spontaneous passage or by active therapeutic intervention. The former depends on the relation of the stone size to the narrowest diameter of the urinary tract, in general the ureter. According to Ueno et al (1977) stones with a length of over 12 mm or over 9 mm in diameter have little prospect of passing spontaneously; with an iatrogenic stricture or a congenital anomaly, such as an abnormal ureteropelvic junction, even smaller stones will be retained.

In principle, therefore, active treatment is indicated for every symptomatic stone that will not pass. Naturally the age and state of health of the patient must be taken into account, but the low morbidity of modern treatment options, which usually do not even require general anaesthesia any more, permit a liberal view to be taken even in high-risk patients.

The need for aggressive treatment may appear more questionable with asymptomatic stones; in particular when their removal implies intricate intervention; even staghorn calculi may remain 'clinically silent' for long periods of time, only to be detected through investigations for loin pain or recurrent urinary infection. However stable the clinical picture may remain for years at a time, the stone ultimately destroys the kidney. Blandy and Singh (1976) traced the fate of 40 patients with stones of this type which were not removed within a 20-year period. Sixteen patients lost the affected kidney, usually as an emergency procedure for pyonephrosis, and 11 patients ultimately died as a result of their renal calculi. Despite a high tendency to form recurrent stones, the results of surgical removal are significantly better (Boyce & Elkins 1974, Wickham et al 1974, Blandy & Singh 1976, Gil-Vernet & Caralps 1978, Marberger 1989), so that conservative treatment of 'asymptomatic' staghorn stones is not justified.

Simple pelvic stones have a high tendency to obstruct and therefore rarely remain asymptomatic; they should be treated when diagnosed. The decision is more debatable with calyceal stones, which are frequently detected by chance and may remain unchanged and asymptomatic for years. Obviously, invasive open surgery is not justified, and even the morbidity of percutaneous surgery rarely justifies their removal. According to their size, most of these stones should be passed spontaneously if they pass into the renal pelvis. Hübner et al (1984) followed the fate of 63 patients with asymptomatic calyceal stones. Within a 7-year period more than half of the patients became symptomatic and 40% required a therapeutic intervention, usually to remove the calculus now impacted in the ureter. With the availability of painless second generation lithotriptors with small high-pressure zones, such as piezo-electric lithotriptors, the situation has changed. With continuous ultrasound focusing during treatment, the focal area can be pinpointed on the stone so that trauma to the surrounding soft tissues is minimized. Calyceal stones can now be treated at significantly less morbidity. In the experience of Marberger et al (unpublished date) with 106 patients treated for stones of this type, there was only a 13% rate of renal colic, and 94% of the kidneys were stone free 3 months after treatment. Analysis of the failures suggests that the stones were probably submucosal calcifications; with precise ultrasonography at various angles the intraparenchymal position should in general be recognized, and the absence of fragment movement during treatment confirms this further. With nephrocalcinosis, such as in sponge kidneys from tubular acidosis, most of the calcifications lie within the collecting ducts. Extracorporeal shock wave lithotripsy (ESWL) is only indicated when larger stones have wandered into a calyx or the pelvis, so that they can be identified and focused.

Up to 90% of all symptomatic ureteral stones are ultimately passed spontaneously (Bandhauer 1970). If it appears likely that the stone will pass spontaneously because of its small size, conservative management with symptomatic treatment of pain is clearly the appropriate form of management. The kidney tolerates short-term obstruction of a severe degree without a permanent impairment of function. The passage of the stone through the ureter may, however, take weeks and may be accompanied by recurrent episodes of renal colic. Although basically harmless, anyone who has ever experienced renal colic can easily understand the patient's apprehension concerning another attack of pain, and the desire to avoid it. The low morbidity of the newer treatment options, in particular painless ESWL in situ, justifies a more active approach today. If a stone is not passed within 4 weeks, especially with signs of obstruction, or if the patient experiences recurrent renal colic, active treatment by ESWL or endoscopic manipulation is indicated even for smaller stones today. With larger stones, in particular when they are impacted in the proximal ureter and are easy to localize, early treatment after the first attack of pain by ESWL in situ is recommended. Although many of the stones treated in this way might ultimately also pass spontaneously, the overall morbidity of this active approach is lower than that of conservative management.

TIMING OF THERAPEUTIC INTERVENTIONS

The urgency to intervene actively depends on the symptoms, on the size and position of the stone, on the degree of obstruction and on the presence or absence of urinary tract infection.

If anuria is caused by postrenal obstruction, early relief of this obstruction is essential; morbidity and mortality both rise in direct relation with the level of azotaemia (Wilson et al 1979). In general, this can be achieved with a low risk to the patient by performing a percutaneous nephrostomy under local anaesthetic. Definitive treatment is postponed until renal function is returned to normal. If the contralateral kidney is functioning normally and if symptoms are not excessive, there is time enough to plan an elective procedure. In part, this may be determined by the availability of lithotriptor facilities and waiting lists.

There has been considerable interest in the factors which cause renal damage in ureteric obstruction. The capacity and elasticity of the collecting system (Walker et al 1980) and the flow rate within the system (Djurhuus & Stage 1976) have been shown to be important determining factors. In the presence of complete obstruction, renal pelvic pressure may rise considerably, especially where the pelvis is small and intrarenal (Michaelson 1974, Gillenwater 1979). The consequences of complete ureteric obstruction on renal function have been thoroughly investigated in animal models: urine production, urinary concentrating capacity, potassium excretion and sodium reabsorption all fall within hours, with an initial transient rise in renal blood flow (Gillenwater 1979, Walker et al 1980).

There has also been a new model for the investigation of partial ureteric obstruction (Ryan & Fitzpatrick et al 1987, Ryan et al 1987, 1989). In a large series of experiments, these authors showed that in partial ureteric obstruction there is an initial rise in pressure which quickly returns to normal. The provoked intrarenal pressure remains high; there is a subsequent decrease in renal blood flow, affecting particularly the outer cortex, with apparent shunting of blood to the inner cortex (Grace et al 1989). It would appear, therefore, that the damage that occurs in partial ureteric obstruction is related to alterations in blood flow and not, as was assumed, to pressure rise.

The reversibility of functional damage depends mainly on the duration and degree of obstruction. In an experimental study (Leahy et al 1989) found that in severe partial ureteric obstruction, ureters obstructed for 60 days had recovered 8% of their function by 1 month following relief of the obstruction; if the obstruction had existed for 1 month, 31% of the total function returned at 1 month following relief of the obstruction; if the partial obstruction had existed for 2 weeks, function did not appear to be interfered with. Holm-Nielsen et al (1981) found similar results when they investigated 72 patients with severely obstructed kidneys. Renal function recovered completely if the obstruction was relieved within 2 weeks, whereas after 2–4 weeks, 3 out of 17 kidneys were permanently damaged and this quota rose to 11 out of 33 after obstruction of 4 weeks duration. As long as there is no infection, severe obstruction may be tolerated for 2–3 weeks without risking permanent renal damage. The message from these studies is that, unless there is a reasonable chance of a spontaneous passage of the obstructing stone, a significant delay in treatment is inadvisable.

The danger to the kidney from obstruction rises dramatically in the presence of infection (Holm-Nielsen et al 1981). Bacteria proliferate within an obstructed system and may produce pyonephrosis, severe parenchymal destruction and Gram-negative septicaemia within hours. Symptoms of an infected and obstructed kidney, such as fever and rigors, therefore demand urgent action to relieve obstruction. Gram-negative endotoxic shock may quickly develop, and this is a condition with a mortality of up to 50% in spite of appropriate therapy. Antibiotics alone will not control the situation, even when the causative organism and its sensitivity are known, unless adequate drainage of urine is provided. This must therefore be accomplished within hours as an emergency procedure (Fingerhut et al 1982). It is best achieved by percutaneous nephrostomy. Ureteral catheters drain poorly and urine output from the infected kidney cannot be monitored. In general, the kidney is therefore drained with a thin nephrostomy placed percutaneously under local anaesthesia. Definitive treatment is deferred until infection is under control and the patient has recovered. Although occasionally it appears tempting to relieve obstruction by an immediate endoscopic procedure, for example ureteroscopy for a prevesical stone, this should be avoided. Any increase in intraluminal pressure from forced irrigation may result in endotoxaemia and life-threatening septic shock.

Occasionally an infected and obstructed kidney causes no acute symptoms. Systemic toxic manifestations, such as loss of appetite and weight, anaemia and a deteriorating general condition then ultimately lead to the diagnosis of pyonephrosis (see Fig. 9.14). In this situation it is usually difficult to determine the duration of obstruction and the degree of renal destruction. The kidney usually shows no excretion of dye on intravenous urography, and renal radioisotopes are quite misleading with regard to the functional recovery of the organ. If renal ultrasonography or computerized axial tomography demonstrate complete destruction of the renal parenchyma, and the contralateral kidney is normal, nephrectomy is indicated. Where the situation remains unclear, a percutaneous nephrostomy is inserted under local anaesthesia. It provides drainage, permits urine sampling for culture and sensitivity testing and provides an access for antegrade nephrostograms. Renal function can be estimated by the urine output, and the concentrating ability and endogenous creatinine clearance through the nephrostomy tube. If function recovers, definitive stone treatment is performed after infection is controlled and renal function is stabilized. When there is no recovery within 3–4 days, nephrectomy is indicated.

Finally, about 60% of all perinephric abscesses result from infected renal or ureteral stones, either by direct extension of parenchymal infection or from extravasation of the infected urine after spontaneous perforation of the collecting system (Truesdale et al 1977). The diagnosis is confirmed by computerized axial tomography. Immediate surgical drainage is mandatory. Since in this situation the extent of inflammatory changes rarely permit precise anatomical dissection, the stones are best left in situ and treated at a later date, once the abscess has been eradicated.

The overall therapeutic aim of renal stone therapy must be complete removal of all calculi and restoration of normal urinary drainage with minimal morbidity. The individual approach chosen should not centre on rigid rules, but rather be adapted to the individual situation, taking into account the anatomical conditions, the size and distribution of the stones and clinical circumstances. For optimal results, ESWL, endourological techniques and open surgery should be freely available and be selected depending on which is more suited in the specific situation.

In the rare situation that open surgery is needed, the procedure should definitely solve the clinical problem; the rationale of removing only the easily accessible part of a staghorn stone by pyelolithotomy and treating residual fragments by subsequent ESWL fails to produce results which justify the magnitude of the intervention (Meyer et al 1987). Depending on the type of lithotriptor used, in particular the properties of its shock waves, its focal area and pressure intensity, and the capacity of the collecting system to transport the stone debris, ESWL treatment of large or multiple stones may be staged. At the price of a higher retreatment rate, most second generation lithotriptors have a smaller focal region, so that less soft tissue is exposed to high pressures and the procedure becomes anaesthesia free.

The interval between treatments depends on how much of the debris from the previous session was passed, and on any damage from the shock waves to the renal parenchyma. The latter aspect has received considerable experimental and clinical attention (see Ch. 3) and mainly depends on the type of lithotriptor used and on the amount of energy administered. As a rule, haematuria should have subsided completely and the kidney should appear normal at ultrasonography before another treatment.

ESWL and endourology are frequently combined with a large variety of treatment protocols (see Ch. 7). The time interval between the two procedures depends on potential complications from using ESWL too early after percutaneous procedures, or vice versa. Decisive are, again, physical properties of the lithotriptor used, but treatment should not be continued before haematuria has completely subsided. Because of tissue oedema, stone localization by ultrasonography is difficult for 2–3 days after percutaneous manipulation, so that ESWL with lithotriptors using ultrasonography has to be delayed for at least this time. In general, the key to successful and safe timing lies with careful patient observation and individualized treatment, rather than adhering to strict rules.

With a renoureteral unit having calculi at various levels, treatment should be directed at removing the most distal calculus first. If this fails for any reason, there must be a drainage procedure of the obstructed kidney, if necessary by a percutaneous nephrostomy.

Under special circumstances, in particular with bilateral ureteral stones or a ureteral and contralateral small pelvic stone, simultaneous treatment may be justified, provided drainage is guaranteed by ureteral stents or nephrostomies (see Figs 9.12, 9.17). This applies particularly to uric acid stones, which are frequently multiple. Although dissolved readily by oral alkalinization of the urine, the process is speeded up by the multifold increase of stone surface as the stone is disintegrated by ESWL. If, at routine ultrasonography, other calculi are noted and a lithotriptor which uses ultrasound for stone localization is available, all stones are treated in the same session. The availability of dissolution therapy does not preclude the need for ureteral stenting; because the fragments cannot be seen on plain radiographs it is not possible to see at what level they cause obstruction.

With stones in solitary kidneys, the indications for therapeutic intervention are only altered in that any risk of obstruction or infection renders treatment even more urgent. Naturally there is a greater threat of azotaemia and anuria by transient obstruction from stone debris after ESWL, but this is minimalized by prophylactic ureteral stenting. Even where more aggressive treatment is needed, as for example an infected staghorn stone in a solitary kidney, the standard treatment principles apply. The only difference between this situation and that of a patient with a normal contralateral kidney is that there is a need for longer interludes between the various stages of treatment in order that the kidney has time to recover. Even advanced renal failure does not necessarily exclude stone treatment. Relieving obstruction and controlling infection frequently stabilizes renal function, and chronic haemodialysis may be avoided (see Fig. 9.15). Even in dialysis patients, there may be an indication to remove obstructing stones in order to preserve residual renal function and reduce the risk of pyonephrosis, thus significantly improving quality of life.

With bilateral stones, either the side on which symptoms are greater, or the kidney which is more threatened by obstruction is treated first. In the case where the stone on one side is technically more difficult to treat than the other, for example where there is a large, branched stone on one side and a simple pelvic stone on the other, removal of the simple stone first will allow the more demanding procedure to be undertaken in the knowledge that there is a functioning contralateral kidney. Where preserving a kidney is of doubtful merit, the opposite side should be treated first, since nephrectomy may appear a less grave step if the first procedure has proceeded without mishap.

DIAGNOSTIC EVALUATION AND PATIENT PREPARATION

Change in the management of calculi from open stone surgery towards ESWL and endourology has left a marked impact on the magnitude of the preoperative diagnostic work-up. In 'surgical' times, failure to locate the calculus often meant that a procedure would be undertaken which had a high morbidity with no certainty of success. The new techniques permit immediate correction of a diagnostic error without significance to the patient, especially if the procedure is performed without anaesthesia. Nevertheless, unequivocal information on the position, number and shape of the calculi, on their position within the collecting system, on the function of the affected kidney and on complicating factors such as urinary infection, hypertension or bleeding diatheses must be obtained before any therapeutic intervention. The metabolic work-up is detailed in Chapter 11 and will not be discussed here.

An intravenous urogram, if necessary supplemented with tomograms, with delayed, oblique and postmicturition films usually clarifies the anatomical situation and gives an estimate of renal function. It is essential that the position of the suspected calculus within the renal collecting system is documented. Ultrasonography is the ideal imaging technique for this purpose and should be performed routinely before any therapeutic intervention. It also has its pitfalls, as for example with calcified intrarenal aneurysms, and expertise in reading the findings in combination with the clinical situation remains essential for the urologist who treats stones. Where a collecting system is not clearly visualized, it may be necessary to delineate it by retrograde ureteropyelography. If obstruction is present, it must then be relieved immediately either by stone removal or drainage, in order that infection in the obstructed system may be avoided. Where this can not be achieved reliably, primary percutaneous nephrostomy for drainage and an antegrade nephrostomogram is to be preferred. Computerized tomography is helpful for defining the situation in complicated calculi, such as staghorn stones with perinephric abscesses.

However clear the situation may appear from the preoperative work-up, a plain radiograph must routinely be obtained before any major intervention. Even an apparently immobile stone may change its position without symptoms and may then require another approach.

Stone mass and hardness have implications on the choice of treatment. The former can be measured precisely on anteroposterior and coronal plain films, which should routinely be obtained. The size of radiolucent stones can be estimated by ultrasonography or by retrograde or antegrade nephrostograms. Predictions on the resistance of calculi against shock waves or contact lithotripsy based on their radiographic appearance have proven to be highly unreliable in the author's experience. Dretler (1988) correlated mononuclear laminated structures with hard, difficult-to-fragment calcium-oxalate-monohydrate stones, and a striated structure with easily fragmented calcium-oxalate-dihydrate stones. Frequently stones are composed of both constituents and, even with a chemically uniform composition, the density of the stone varies considerably depending on its porosity. Over 90% of all stones not visible on standard plain films are mainly composed of uric acid, but poorly radiopaque struvite, matrix or cystine stones may appear radiolucent on poor quality plain films. Computerized tomography permits more precise attenuation, even when the coefficient of linear X-ray absorption is only slightly above water and therefore invisible on plain films (Greenberg et al 1982). Depending on the radiopacity of the stone, the limit of resolution is reached at a diameter of 1–3 mm. By examining the pixel pattern and the absolute CT values measured under defined exposure conditions, uric acid stones may be distinguished from struvite and cystine stones with an accuracy of at least 70% (Yokoyama et al 1982, Mitcheson et al 1983). For clinical practice this is too elaborate and it is simpler to predict the probable composition of the stone by urine culture and semiquantitative determination of urinary cystine excretion.

The intravenous urogram already permits a very rough estimate of renal function, provided dye is excreted on the affected side. With a non-opacified system and a normal contralateral kidney, functional evaluation exerts the main influence on therapeutic management, particularly as to the question whether relieving obstruction is likely to improve function and thus render a stone-bearing kidney of borderline function worth saving. Renal ultrasound provides a rapid estimate of the amount of remaining parenchyma: where it is thinned out to less than 3 mm and only a hydronephrotic sack is visible, organ preservation is futile. A parenchyma of normal thickness suggests that the reason for absence of excretion is an acute one and that there is a good chance of recovery of function. When complete ureteric obstruction is relieved by percutaneous nephrostomy, the glomerular filtration rate of the stone-bearing kidney can be estimated most reliably by endogenous creatinine clearance using the urine from the nephrostomy tube.

Otherwise, the functional capacity has to be evaluated by split radioisotope studies. ^{131}I-Hippuran renography using a gamma camera and subtraction of extrarenal activity as estimated from a whole body uptake curve (Oberhausen 1971), or from a second tracer radionuclide (Britton & Brown 1968), permits rough calculation of the contribution of each kidney to total renal clearance. With acute obstruction this technique overestimates function (Doppelfeld & Weissbach 1979), but with chronic obstruction there is good correlation with values obtained before and after decompressing an obstructed kidney by nephrostomy (Alken 1980). The technique was widely utilized for follow-up studies (Marberger & Eisenberger 1980, Chaussy & Schmiedt 1986), but it only states the function at the time of examination and provides no information on the functional reserve (Walker et al 1980). The use of ^{123}I-Hippuran reduces radiation hazards and permits the investigation to be combined with sequential dynamic scintigraphy, e.g. diuresis renography to quantify obstruction. Technetium dimercaptosuccinic acid (^{99}Tc^{m}DMSA) is fixed to the tubular epithelium within 1 hour, its distribution being proportional to the differential renal blood flow (Daly et al 1979). The substance is extensively bound to plasma proteins and shows minimal early excretion, so that the urine in the collecting system is virtually devoid of activity, even with complete obstruction. The technique permits good assessment of the remaining parenchyma in obstructed kidneys, using static scintigraphy (Kawamura et al 1983).

Whether or not a kidney is worth preserving cannot be decided on a strict percentage figure of the residual function, since a variety of other factors, such as the state of the opposite kidney, age and general condition of the patient, the technical difficulty and the complications of organ-preserving stone removal, also have to be considered. As 28% of all patients with unilateral stone disease will experience a stone episode on the opposite side at some time during their lifetime (Williams 1963), and since a residue of only 15–20% of the normal parenchyma still provides renal function, which is in essence superior to dialysis, the decision must favour organ preservation wherever possible. The younger the patient, the less should there be resource to nephrectomy, even where organ preservation carries a high risk of recurrent stone formation. For a patient of over 70 years of age with a staghorn calculus in a severely damaged kidney, with a normal opposite kidney, a nephrectomy may, on the other hand, be more reasonable, as it solves the problem for years with a low complication rate. In general, the principal indication for nephrectomy today with urolithiasis remains pyonephrosis, i.e. an organ completely destroyed by suppurating infection (Blandy & Singh 1976).

Urinary infection causes a significant increase in the complication rate from pyelonephritis, septicaemia and perirenal infection. A quantitative urine culture should therefore be obtained routinely before any therapeutic intervention. If infection is proven, it should be treated by specific antibiotics based on the sensitivity pattern for at least 48 hours prior to stone treatment. *E. coli* is the most common organism identified with uncomplicated renal calculi. *Proteus* and *Pseudomonas* predominate in the case of recurrent stones and after instrumentation whereas *E. coli* accounts for only one-third of the infections in this group (Cox 1974). Four-fifths of all staghorn calculi are infected at the time of diagnosis: Cox (1974) cultured *E. coli* in only 13%, whereas 23% had *Pseudomonas* and 43% *Proteus*. In general, it is impossible to sterilize an urinary tract in the presence of stones, but the risk of infective complications following treatment is reduced significantly by antibiotic pretreatment. Infected kidneys have to be monitored closely for obstruction and early decompression by percutaneous nephrostomy is indicated wherever obstruction becomes apparent.

Reduced renal function is not a contraindication to stone removal, but the potential complications of the various treatment options have to be considered. With a creatinine clearance of less than 20 ml/minute the ability of the system to eliminate stone fragments after ESWL drops sharply. Despite a normal prothrombin time, partial thromboplastin time and platelet count, patients with advanced renal failure often have a prolonged bleeding time which results in a clotting defect. Percutaneous procedures and ESWL carry a higher risk of haemorrhage, which is further increased by the hypertension commonly observed in these patients. Naturally, any insult to the renal parenchyma, however small, is deleterious to patients with borderline renal functions. Stone removal by a simple pyelotomy, without touching the renal parenchyma, may therefore be preferable over the less invasive techniques routinely used in the same situation with normal renal function.

When a patient with reduced renal function is selected for a therapeutic intervention, an exact estimate of the residual function, best evaluated by determining the endogenous creatinine clearance, is the first step (Wilson et al 1979). Hypertension must be treated and water and electrolyte imbalances carefully corrected to achieve the best possible pretherapeutic homeostasis. Patients whose creatinine clearance lies below 15 ml/minute may require measurement of central venous or pulmonary artery pressure before this can safely be achieved. Because of the risk of cardiac arrest, especially during induction of anaesthesia, hyperkalaemia must be regarded as the most dangerous electrolyte imbalance. It requires preoperative treatment by ion exchange resins, or, if necessary, by haemo- or peritoneal dialysis. Metabolic acidosis which potentiates the cardiac effects of hyperkalaemia does not require full correction, but the serum bicarbonate levels should be maintained above 20 mEq/l. If the risk of volume overload prevents this from being achieved by the administration of sodium bicarbonate, the patient may still require dialysis. Patients with renal insufficiency are usually well adapted to their anaemia, but the haematocrit should be raised above 25% before any intervention by transfusing packed red cells. The clotting disorder is best corrected by giving standard Red Cross Cryoprecipitate immediately preoperatively (Janson et al 1980).

The anaesthesia of patients with renal failure is beyond the scope of this presentation, yet express attention should be drawn to the hazards of methoxyflurane, ether, cyclopropane and muscle relaxants throughout the procedure, and of proper postoperative analgesia.

Properly prepared patients on chronic haemodialysis survive routine surgical procedures with a mortality only slightly above that of normal patients (Wiehle et al 1981). The main problems arise from perioperative fluid overload and haemorrhage from heparinization during haemodialysis. The operation must therefore be timed to fit between dialysis sessions in an optimal fashion, dialysis being avoided for the first 48 hours postoperatively. Minimal heparinization during perioperative dialysis is associated with fewer bleeding complications than regional heparinization with simultaneous infusion of heparin and protamine (Kasike & Kjellstrand 1983). Wound healing problems may be significantly reduced by atraumatic techniques, intraoperative irrigation of the wound cavity with an antibiotic solution and adequate hyperalimentation by nasogastric tube or intravenously (Giacchino et al 1981).

Transplanted kidneys may form stones, especially if hypercalcaemia persists because secondary hyperparathyroidism has resolved incompletely after transplantation. Since these are essentially immunosuppressed patients with solitary kidneys, the hazards of obstruction and infection exceed those for normal kidneys. Untreated stones may be a cause of death in these patients (Rosenberg et al 1975). Apart from the reversal of the biochemical cause of stone formation, which may involve parathyroidectomy, the stone has to be removed. If it can be localized by lithotriptor, ESWL is a treatment of choice. Otherwise it is to be removed percutaneously. Even if the urine is sterile, prophylactic perioperative antibiotic coverage is recommended.

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Chapter 3

Extracorporeal shock wave lithotripsy of renal stones

A D Jenkins

Introduction

Lithotripsy, whether percutaneous or extracorporeal shock wave, has revolutionized the treatment of surgically active urolithiasis. Although percutaneous nephrolithotripsy (PCNL) was introduced clinically before extracorporeal shock wave lithotripsy (ESWL), ESWL rapidly supplanted open surgery and percutaneous lithotripsy as the primary treatment of surgically active urolithiasis (Alken et al 1981, Segura et al 1983, Chaussy et al 1982, Drach et al 1986). Nevertheless, one should not assume that ESWL is the best treatment for all urinary tract calculi. Endoscopic procedures, antegrade or retrograde, are often better when used alone or concurrently with ESWL. In some situations open surgery is the best treatment.

THEORETICAL AND EXPERIMENTAL FOUNDATION

ESWL was the culmination of a 10-year research effort by Dornier System GMBH and the Department of Urology and Institute for Surgical Research of Ludwig Maximilian's University (Munich, Germany). The programme began with the investigation of shock wave damage to gas-filled satellites struck by micrometeorites and supersonic aircraft struck by raindrops (Chaussy & Fuchs 1987a). The suggestion was made that shock waves might be useful for the disintegration of kidney stones. Subsequent studies in animals demonstrated that extracorporeally generated shock waves could safely and effectively fragment renal calculi.

Two-hundred and six patients were treated over a 2-year period beginning in 1980 (Chaussy et al 1982). No patient had infection stones or radiolucent stones. All the stones were less than 1.5 cm in diameter. General endotracheal anaesthesia was used for the first 14 patients, but epidural anaesthesia was used for the remainder. Fifteen patients (7%) required more than 1 ESWL treatment to achieve adequate fragmentation. Seventy-five per cent of the stones were in the renal pelvis, while 20% were in the ureter. The stone-free rate 3 months after treatment was 89%, while 11% of the patients had particles that were small enough to pass spontaneously. Two patients with ureteral calculi and 2 patients with renal calculi required open surgery for removal of their stones.

Shock wave lithotripsy has become so common that most urologists understand the difference between shock waves and ultrasound. When ESWL was first introduced, however, most urologists were more familiar with the use of ultrasound to fragment calculi through percutaneously placed endoscopes. This technique uses high-frequency sound vibration (23 000 to 27 000 Hz) (Segura 1985). Ultrasound consists of a sinusoidal wave with alternating positive and negative deflections and a well-defined wavelength (Fig. 3.1). The vibration is transmitted down a rigid hollow steel rod. The rapid longitudinal vibrations of the ultrasound probe break the stone into small pieces that are evacuated from the kidney.[1]

Shock waves consist of a single positive pressure front that has a steep onset and a gradual decline (Fig. 3.2). The high pressures associated with a shock wave lead to a discontinuous distortion of the leading edge of the wave. Shock waves travel through water at a velocity that is slightly greater than that of sound through water.

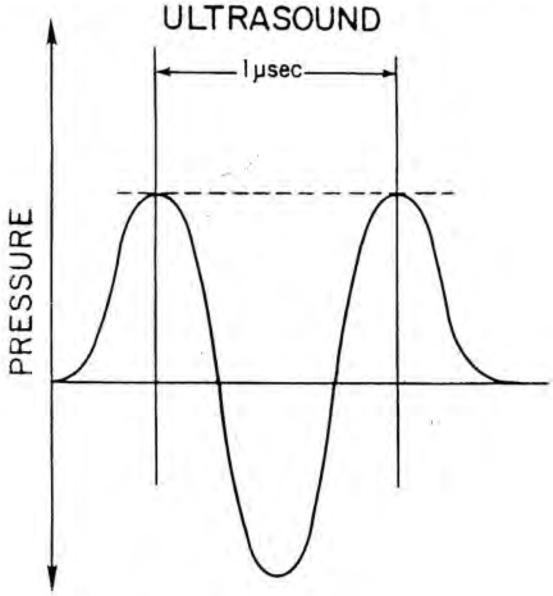

Fig. 3.1

Representative ultrasound pulse with a sinusoidal wave form and a fixed wave length. (The frequency of this pulse is 1 million Hertz or 1 MHz. This frequency has the same order of magnitude as that of diagnostic ultrasound, but is much higher than that used for fragmented stones through percutaneous nephroscopes.) (Reproduced with permission from Chaussy & Fuchs 1987b.)

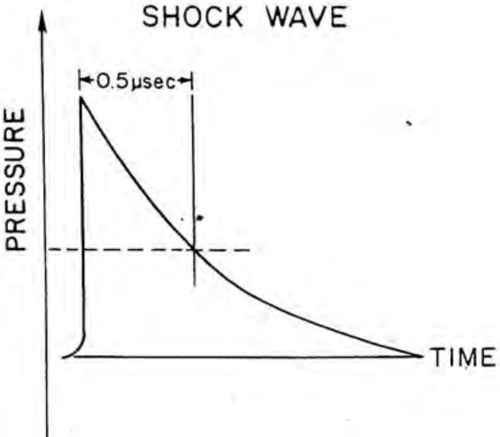

Fig. 3.2

Representative shock wave pulse demonstrating the rapid rise and gradual fall of the pressure. Shock waves travel with the discontinuous sharp pressure pulse as the leading edge. (Reproduced with permission from Chaussy & Fuchs 1987b.)

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[1] Diagnostic and therapeutic ultrasound use frequencies that are in the megahertz or 1 million Hz range. Both diagnostic ultrasound and lithotripsy ultrasound are 'ultrasound' because their frequencies are greater than the highest frequencies audible to most humans.

Shock waves cannot be described by a single frequency, but can be described in terms of a range of frequencies associated with a fundamental frequency (about 0.5 MHz for most extracorporeal lithotriptors).

Several means have been used to generate shock waves. Even before the advent of extracorporeal shock wave lithotriptors, many urologists used electrohydraulic lithotriptors to fragment calculi through nephroscopes as an alternative to ultrasonic percutaneous lithotripsy. These electrohydraulic devices consist of two electrodes, usually oriented in a coaxial fashion (Kahn 1985). A small spark discharge between the two electrodes vaporizes a small amount of water and creates a tiny bubble that rapidly expands and collapses. This rapid expansion and collapse creates a spheroidal shock wave that expands. If such an electrode is placed within a few millimetres of a calculus, small cracks will appear in the stone after several shock waves. The stone can be completely fragmented if enough electrode discharges are used. The disadvantage of this technique is that it requires placement of the electrode very near the stone and the spark discharge may injure tissue. Nevertheless, the original extracorporeal shock wave lithotriptors and the EHL probes use basically the same technique to generate shock waves that ultimately fragment stones.

Dornier was the first company to develop a clinically useful lithotriptor and they also used an underwater spark discharge to generate their shock waves. Since the energy of any given area of a spherically expanding shock wave falls rapidly as the distance from the source increases, Dornier devised a focusing system to concentrate the shock waves (Fig. 3.3) (Chaussy & Fuchs 1987b). Dornier placed the electrode tips at one focus of a reflector that had an ellipsoidal shaped cross-section. A spherical shock wave is generated by the underwater spark discharge at the first focal point (F_1), but the ellipsoidal reflector reflects and focuses the spheroidal shock waves on the second focal point (F_2). A stone can be placed at F_2 and fragmented by the shock waves. Not only does the reflector concentrate the shock wave pressure at F_2, but it also permits the shock waves to enter a patient's skin through a wider area. This can reduce injury to the tissues between the stone and the shock wave entrance site, any associated pain and the need for anaesthesia.

Dornier's initial goal had been to use only a few shock waves to fragment a stone. Stones could be fragmented with fewer than 10 high-energy shock waves, but the fragments were large (Chaussy et al 1982). Subsequent experiments demonstrated that the use of many more lower powered shock waves would result in many more, but much smaller, particles that could easily pass through the ureter. The production of smaller particles with lower energy shock waves is the basis for some of the claims of the manufacturers of newer lithotriptors (such as Siemens and Wolf).

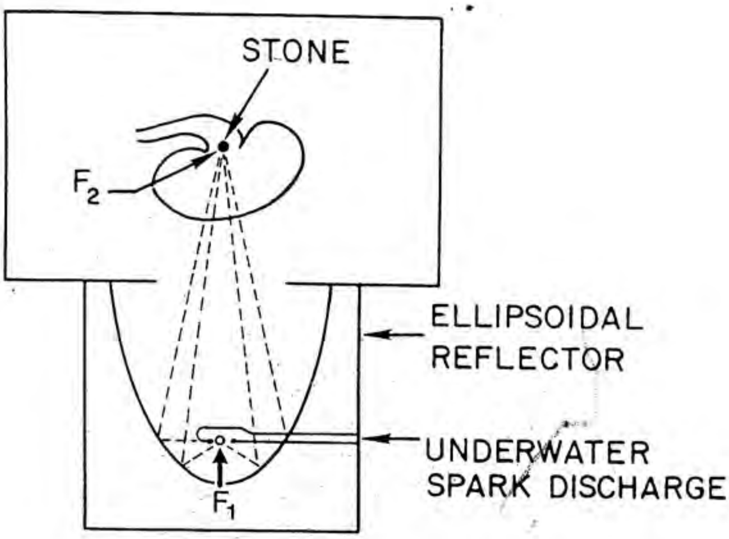

Fig. 3.3

Schematic of the Dornier electrohydraulic lithotriptors. Spherical shock waves are produced at F_1 by discharge of the underwater electrode. The spherical shock waves are focused at F_2 by the ellipsoidal reflector. A patient's stone is placed at F_2. (Adapted from Chaussy & Fuchs 1987b.)

The mechanism of stone fragmentation by shock waves is not understood entirely, but two mechanisms are thought to be involved. When the shock waves produced by a Dornier lithotriptor converge on the second focal point, they have a concave configuration. Shock waves can be reflected and refracted at acoustical interfaces just as light waves can be reflected and refracted at optical interfaces. The interface between a stone and the surrounding urine or renal tissue is one such acoustical interface. When the concave-shaped shock wave strikes the leading edge of a stone, a portion is reflected (Fig. 3.4) (Chaussy & Fuchs 1987b). The interface between the primary and reflected shock wave creates a strong tensile stress that literally tears off a layer of stone material from the leading edge of the stone. Since shock waves will travel through stone material easier than they will travel through fluid, much more of the shock wave is reflected from the back surface of the stone. The original shock wave and the reflected shock wave create a large tensile force that also tears a layer of stone material from the back surface of a stone. The passage of multiple shock waves through a stone ultimately will lead to the pulverization of the entire stone.

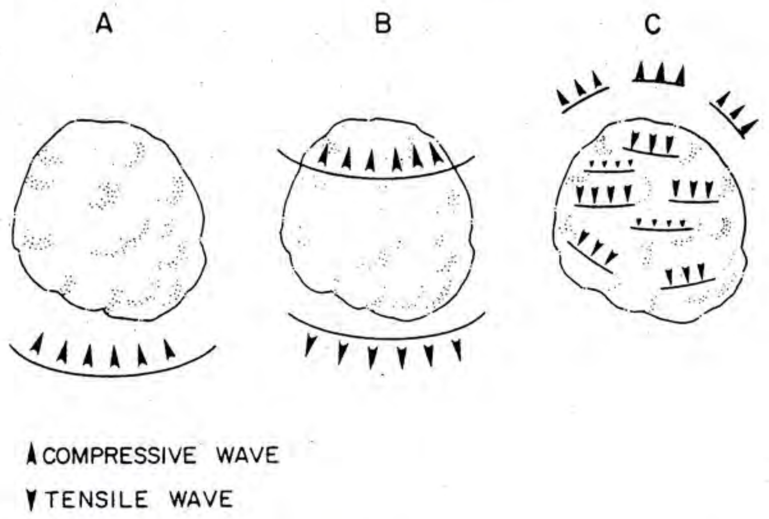

Fig. 3.4
Shock wave-induced spalling on the front and back surfaces of a representative stone. (Adapted from Chaussy & Fuchs 1987b.)

This phenomenon is called spalling and is depicted graphically in Figure 3.5 (Rinehart 1967). A shock wave with a discontinuous leading edge is shown travelling from left to right. When this shock wave strikes an acoustical interface, a portion of it is reflected. The reflected wave has a tensile component. The summation of the interaction between the original compressive shock wave and the reflected tensile shock wave creates an even greater discontinuity just beneath the surface of the stone. This layer of stone material is torn off.

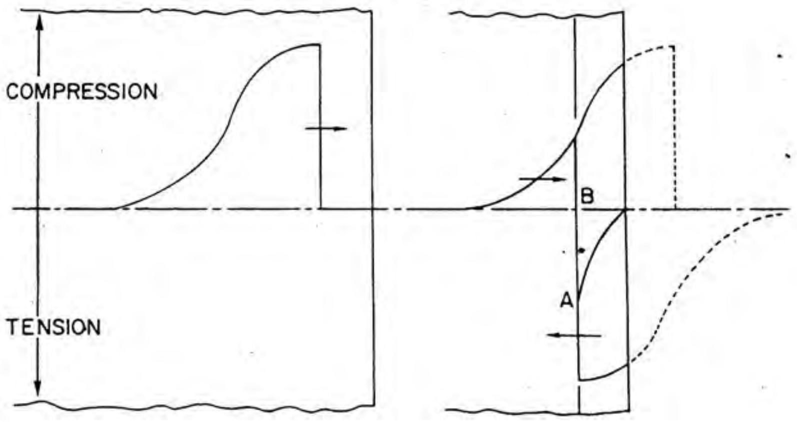

Fig. 3.5
Formation of a tensile shock wave following reflection of a compressive shock wave at an acoustic interface. (Redrawn from Rinehart J 1967 *International Symposium on Stress Wave Propagation in Materials.* John Wiley and Sons Inc, New York, pp. 247–269.)

Another potential mechanism of stone fracture is the formation and subsequent collapse of cavitation bubbles (Crum 1988). The formation and collapse of cavitation bubbles will erode propellers on ships. Cavitation bubbles will form in a liquid when a tensile force exceeds the forces holding the liquid together. These cavitation bubbles are spherical in shape and may oscillate in size for a period of time before collapsing in on themselves (Lauterborn & Hertschel 1985). If the bubbles are adjacent to a surface, however, extremely powerful microjets can form. These microjets can damage stones and tissues (Fig. 3.6).

The cavitation jets are so powerful that they can produce holes in sheets of aluminium foil and produce small dents in brass plates. Calculated pressures generated by cavitation jets are approximately 225 MPa. The yield strength of metals is between 100 and 500 MPa, while the compressive strength of most stone materials is less than 20 MPa.[2] Some investigators think that cavitation may be responsible for stone breakup on the front face of a stone, where the shock waves enter, while spalling may be responsible for breakup on the back face of a stone, where the shock waves exit. Other investigators think that cavitation bubbles may be responsible for the tissue damage associated with ESWL (Delius 1988).

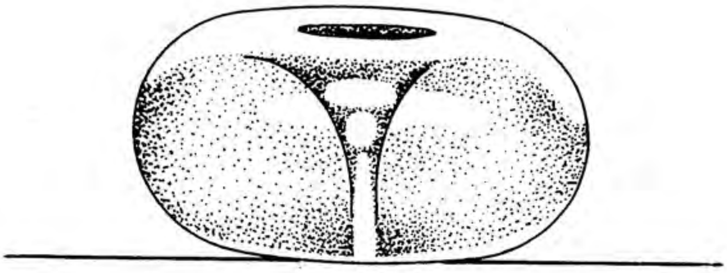

Fig. 3.6

A cavitation bubble is resting on a surface at the bottom of the figure. A cavitation jet is visible travelling through the centre of the cavitation bubble. The force of this water jet can deform metals and may be responsible, in part, for stone destruction and tissue injury. (Adapted from Crum 1988.)

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[2] Pressure can be measured in several units, three of which are atmosphere, bar and Pascal. One atmosphere = one bar = 14.69 psi, 1000 bar = 1 Kbar = 14 690 psi, 10 bar = 1 million Pascal = 1 MPa, and 1 Kbar = 100 MPa.

EQUIPMENT

The first commercially available kidney lithotriptor was manufactured by Dornier. The HM3 ('Human Model 3') uses an underwater electrode for shock wave generation, a rotational ellipsoidal reflector for shock wave focusing, and a biplanar fluoroscopic system for stone localization (Fig. 3.7). The two fluoroscopes are mounted such that the beams intersect at the second focal point. The patients are placed in a gantry-like support that is suspended from the ceiling by a hydraulic cylinder (Fig. 3.8). Patients are strapped into this chair-like device to prevent them from floating out of the water-filled tub. The water is used as a medium to transmit the shock waves from the electrode and reflector to the patient's skin.

The individual shock waves produced by an original Dornier HM3 lithotriptor are not especially painful, but most patients are unable to tolerate the number of shock waves required for adequate stone pulverization without some type of anaesthesia. The vast majority of patients have been treated under general endotracheal or regional anaesthesia. At the University of Virginia more than 90% of patients having ESWL with the Dornier HM3 lithotriptor receive an epidural anaesthetic. Some patients can be treated with local anaesthesia or intravenous sedation, especially if the spark discharge voltage and resultant shock wave pressures are kept low. The anaesthetized patient is placed on the special chair, secured, and lowered into a water bath. The X-ray tubes are mounted beneath the tub and the image intensifiers are suspended in two large canisters above the patient. The orthogonal fluoroscopic system is used to place the stone accurately at the second focus and to monitor stone fragmentation during shock wave delivery.

The patient and the chair are hydraulically moved until the stone is at the second focus, and shock wave delivery is initiated. Since cardiac arrhythmias may occur with random discharge of the electrode, electrode ignition is triggered by the R wave of the patient's electrocardiogram. Shocks are given in groups of 100 or 200, interrupted by fluoroscopic verification that the crumbling stone material is still within the focal volume. A typical treatment consists of 1000 or 2000 shock waves and lasts 30–45 minutes. Dornier recommends that a kidney be given a maximum of 2000 shocks during any 24-hour period, although it is not unusual for many urologists to use as many as 2400. A few urologists will use as many as 3000 shock waves, usually to treat impacted ureteral stones.

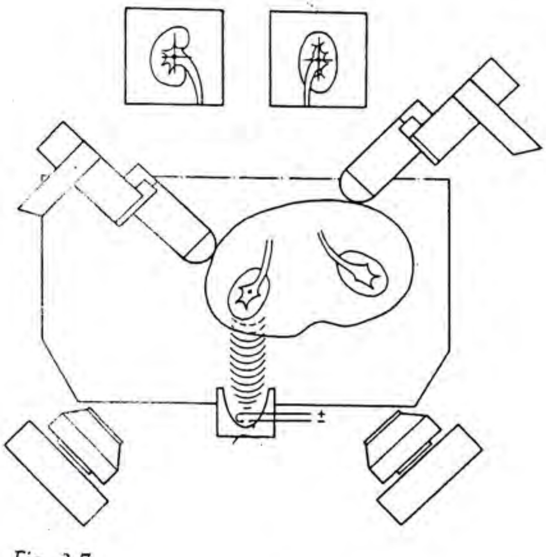

Fig. 3.7

Cross-sectional schematic of a Dornier HM3 lithotriptor with the water bath, underwater electrode, ellipsoidal reflector and biplanar fluoroscopic system. The X-ray tubes are mounted beneath the tub, and the image intensifiers are located in the canisters above the patient. (Reproduced with permission from Chaussy & Fuchs 1987b.)

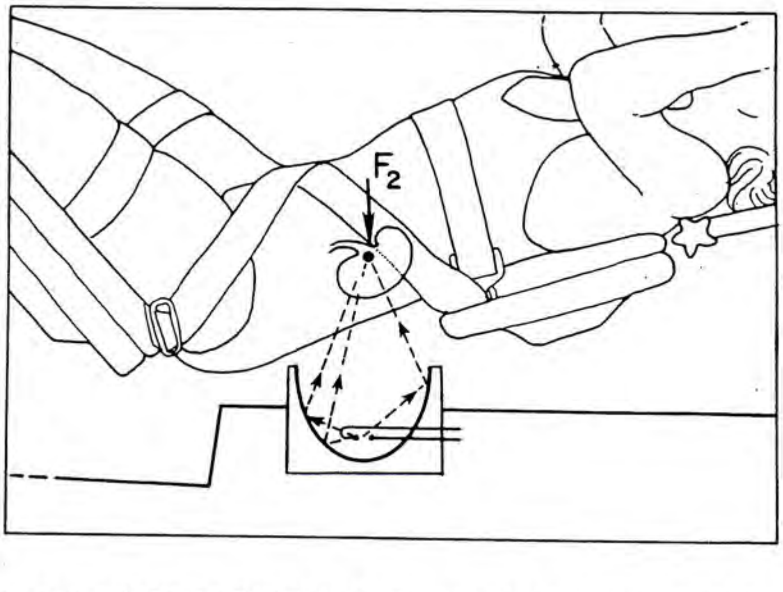

Fig. 3.8

Longitudinal cross-section of a Dornier HM3 lithotriptor. The patient's back is exposed to the shock waves. The patient's arms are placed above the patient's head to pull the lungs away from the kidney. The multiple air–fluid interfaces in the lung make the lungs very susceptible to shock wave injury. For practical purposes this is a problem only in very small children and infants. (Adapted from Chaussy & Fuchs 1987b.)

BASIC LITHOTRIPTOR DESIGN

Any extracorporeal shock wave lithotriptor consists of five basic components or subsystems:

1. Shock wave generation
2. Shock wave focusing
3. Shock wave coupling
4. Stone localization
5. Patient positioning

The shock waves must be generated, focused, and transmitted to the patient. The stone mass must be identified and localized. The patient must be positioned so the shock waves strike the stone with minimal effect on adjacent tissues.

Most lithotriptors are classified by their mechanism of shock wave generation and their localization system. Shock waves have been generated most commonly with an underwater spark discharge. This system is used with the Dornier lithotriptors HM3, HM4, MPL9000 and MFL5000. The spark discharge creates a bubble that expands rapidly and compresses the surrounding fluid. Shock waves can be created with any type of underwater explosion. Shock waves have been generated by a focused laser beam and the discharge of a small quantity of explosive material (lead azide).[3]

Shock waves generated by an underwater explosion have a spherical configuration and must be focused to fragment a stone without appreciable injury to adjacent biological structures. Focusing usually is accomplished by placing the explosive discharge at one focus of a reflector that has the shape of a rotational ellipsoid (Fig. 3.9). The shock waves bounce off the surface of the reflector and are focused at the second focus. Most commercially available lithotriptors use a spark discharge and rotational ellipsoid to create the focused shock waves.

An array of piezoelectric crystals also can be used to generate and focus shock waves (Fig. 3.10) (Marberger et al 1988). Piezoelectric crystals will change their shape when an electric current is applied (or generate an electric current if they are mechanically deformed). Several hundred of these crystals are mounted on a spheroidal plate. Simultaneous activation of these crystals generates a concave shock wave that converges at the centre of the spheroidal surface on which the crystals are mounted. The targeted stone is placed at the central, single focal point. A modification of this system uses a single, large piezoelectric crystal that is mounted on the surface of a spheroidal plate. The vibrations of this crystal are converted to concave shock waves that converge at the central focal area.

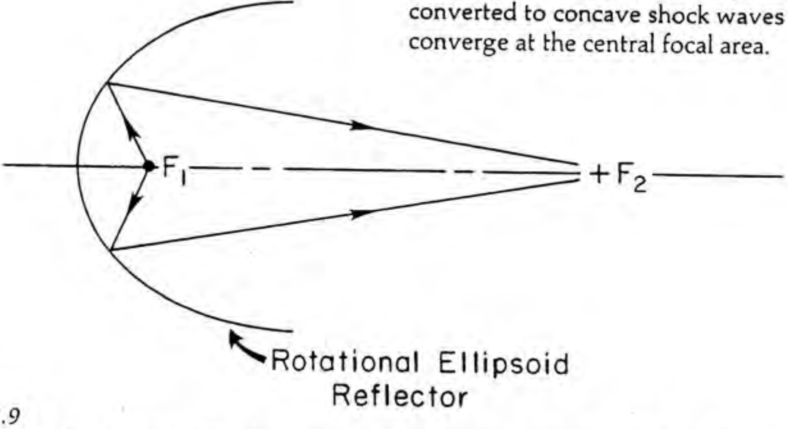

Fig. 3.9

Basic design of an electrohydraulic lithotriptor with a rotational ellipsoidal reflector. Shock waves can be produced at F_1 with an underwater spark discharge, a focused laser pulse, or a microexplosion. (Reproduced with permission from Jenkins A D 1987 1990 Urology Annual. Appleton and Lange, East Norwalk C T, pp. 266–273.)

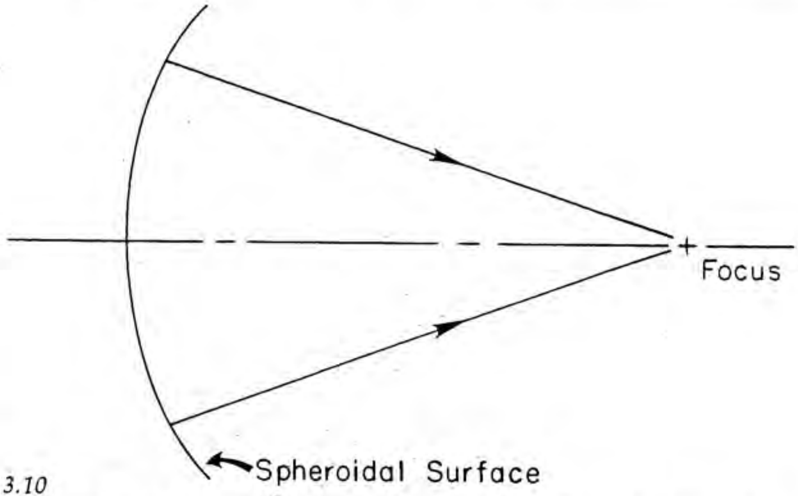

Fig. 3.10

A schematic illustration of a piezoelectric lithotriptor. Numerous small piezoelectric crystals are mounted on the spheroidal surface, or one large piezoelectric crystal is mounted on the spheroidal plate at the central axis. (Reproduced with permission from Jenkins A D 1987 1990 Urology Annual. Appleton and Lange, East Norwalk C T, pp. 266–273.)

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[3] Pulsed dye laser lithotriptors, such as those manufactured by Candela and Technomed, use low-energy shock waves to fragment calculi. Like EHL, pulsed dye laser lithotripsy requires that the transmission device (a quartz fibre) be in direct contact with the stone (Dretler et al 1987).

A third means of shock wave generation is with an electromagnetic coil (Fig. 3.11) (Wilbert et al 1987). A current applied to the coil induces opposing magnetic fields between the coil and an adjacent metallic membrane. The membrane is deflected away from the coil, thereby generating a planar shock wave. The shock wave travels through a water-filled container and strikes a biconcave acoustic lens that focuses the shock waves.

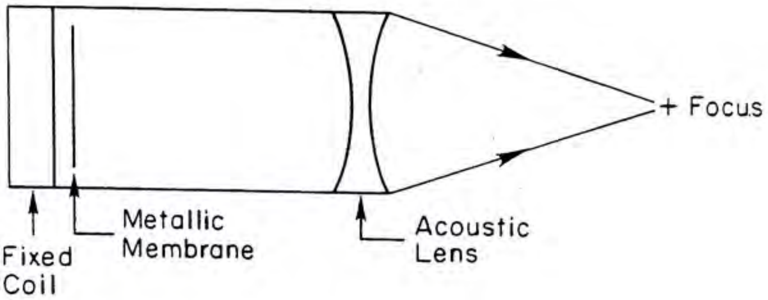

Fig. 3.11

A schematic illustration of the Eisenmenger coil used in the Siemens Lithostar. This electromagnetic principle is used with a different geometric configuration in the Storz Modulith lithotriptor. (Reproduced with permission from Jenkins A D 1987 1990 Urology Annual. Appleton and Lange, East Norwalk C T, pp. 266–273.)

BASIC TECHNIQUE

Dornier

As mentioned above, most Dornier lithotriptors use an underwater spark discharge and a rotational ellipsoidal reflector to create and focus the shock waves. The HM3 lithotriptor was the first commercially available lithotriptor and still is the most prevalent machine. The HM4 is an HM3 without the large water bath. The water bath has been replaced by a water-filled membrane that covers the X-ray tubes and ellipsoidal reflector. Both the HM3 and HM4 use a biplanar fluoroscopic localization system. At the request of the operators, Dornier will retrofit the HM3 and HM4 lithotriptors with a shock wave generator that has a lower capacitance (40 nF versus 80 nF), and an ellipsoidal reflector with a larger aperture. These two changes reduce the maximal focal pressure achievable at F_2 and increase the shock wave entrance area on the patient's skin. The ultimate goal is to reduce the need for anaesthesia.

The Dornier MPL9000 is a lithotriptor that was originally designed for gallstone lithotripsy (Seibold et al 1988). It uses an ultrasonic localization system composed of an independent, articulated arm and an in-line ultrasound transducer. The stones are located initially with the articulated arm. The operator switches to the in-line transducer for the final targeting of the stone. Stone destruction can be monitored with either sonographic system during shock wave delivery. Although the MPL9000 was designed for gallstone lithotripsy, it has been adapted for kidney stone lithotripsy. Dornier plans to offer a fluoroscopic localization system for this lithotriptor.

The MFL5000 was designed as a complete urological treatment system. It has the basic configuration of a cystoscopy table with an integral fluoroscopic and hard copy X-ray system. As with most Dornier lithotriptors, the shock waves are generated by an underwater spark discharge and are focused by a rotational ellipsoidal reflector. Dornier intends to retrofit these machines with an ultrasound localization system.

Siemens

The Siemens Lithostar is the first lithotriptor to use electromagnetic shock wave generation (Schärfe et al 1988). The Lithostar was designed as a multipurpose urological treatment table, but the table top will move only in three orthogonal planes. The table cannot rotate on any axis. The localization system consists of a biplanar fluoroscopy system with the X-ray tubes mounted from the ceiling. One of the fluoroscopic systems provides a standard AP radiographic view that is familiar to all physicians. The other fluoroscopic system has been mounted at an approximate 30° angle from the vertical axis. This fluoroscopic system is used to find the depth of a stone along the AP axis.

Two shock wave tubes are provided with the Lithostar, one for left-sided stones and the other for right-sided stones. The shock wave tubes cannot be used simultaneously, but bilateral tubes permits treating bilateral stones without moving the patient. The focal pressures achievable with the Lithostar ave approximately 60 MPa. (Those available with the Dornier HM3 are approximately 100 MPa.) The lower focal pressures and the larger shock wave entrance area result in a reduced need for anaesthesia. Some physicians have successfully used TENS (transepidermal nerve stimulator) units alone, but most patients seem to be more comfortable with intravenous sedation. The discharge voltages achievable on the Lithostar range from 10 to 19 kV. Another technique that further reduces the need for formal anaesthesia when using the Lithostar is to start the treatment with the voltage at 10 kV. If the voltage is increased gradually (every 50 shocks) without stopping, then the voltage can be increased to 16 or 18 kV without producing appreciable discomfort in patients. The voltage must be reduced and the process repeated if shock wave delivery is halted for any reason, such as repositioning a stone.

Wolf

The Wolf Piezolith lithotriptors are one of three types of piezoelectric lithotriptors that have been developed (Segura et al 1988). (The others are the EDAP LT01, and the Diasonics Therasonic lithotriptor.) The hallmark of all piezoelectric lithotriptors is the need for essentially no anaesthesia. This is thought to be a result of the very large dish on which the piezoelectric elements are mounted. This results in a very large shock wave entrance area on the patient's skin. Although the focal volume of the Wolf Piezolith machines is smaller than that of the HM3, the peak pressure is over 100 MPa.[4]

Stones are localized with an in-line ultrasound unit on the Piezolith 2200, and two off-axis ultrasound units on the Piezolith 2300. One of the disadvantages of all ultrasonic localization systems is that identification and targeting of stones in the ureter is difficult, if not impossible. The basis for localizing ureteral stones is identification of a dilated proximal ureter. This can be accomplished for stones in the upper ureter. Stones in the mid-ureter are very difficult to identify, because the transverse processes and overlying bowel provide numerous confounding echoes. Ultrasound can localize stones in the distal ureter if a full bladder is used as an acoustic window (Marberger et al 1988).[5]

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[4] There is an inverse relationship between the size of the focusing system and the size of the focal volume. The focal volume of the original Dornier HM3 lithotriptor is relatively large. It has the shape of a rotational ellipsoid (or 'cigar') that is approximately 12 cm in length and 2 cm in diameter. The corresponding focal volume for a Wolf Piezolith has a length of approximately 1 cm and a diameter of approximately 2 mm. The Siemens Lithostar has a focal volume between that of the HM3 and the Piezolith.

[5] Recently the Piezolith 2500 with an in-line ultrasound and an in-line fluoroscopy system has become available; the two localisation systems are used alternatively as needed.

TREATMENT OF RENAL PELVIC CALCULI

The ultimate success of ESWL is based, in large part, on its ability to rid patients of renal pelvic calculi. Early investigators found that patients with smaller stones had fewer problems than patients with larger stones. In general, a patient with a renal pelvic stone less than 2.5–3 cm in diameter is an appropriate candidate for ESWL alone (Tegtmeyer et al 1986). Ninety per cent of such stones can be fragmented sufficiently with a single ESWL treatment. Most of the remaining 10% will have satisfactory stone fragmentation after a second ESWL treatment. The ultimate stone-free rate at 3 months in patients with simple renal pelvic calculi is approximately 75% (Drach et al 1986).

These results were achieved with standard Dornier HM3 lithotriptors. Most urologists still consider the original HM3 as the 'gold standard'. Although the promotional material of some lithotriptor manufacturers claims that their lithotriptors do a better job of fragmenting a stone or 'erode' the stone without producing any large fragments, there is no scientific evidence to support these claims. The major differences between the different lithotriptors seems to be in their localization systems, the number of shock waves required to achieve comparable degrees of fragmentation, and the need for anaesthesia.

One of the most troublesome aspects of ESWL is the determination of the adequacy of fragmentation. One of the best indicators of adequate pulverization is dispersion of the sand, but this can occur only if the stone is located in a cavity, such as the renal pelvis, that is larger than the stone. As a general rule, a calcium oxalate stone less than 2 cm in diameter should be sufficiently pulverized with 2000 shock waves at 18–22 kV on a Dornier HM3 lithotriptor. Calcium oxalate monohydrate calculi seem to be more resistant to fragmentation than calcium oxalate dihydrate stones (Dretler 1988). Relatively pure calcium phosphate stones seem to be very resistant to the effects of shock waves, as do cystine stones. Up to 2000 shock waves may be needed to fragment sufficiently a 1 cm cystine stone, although cystine stones that have newly formed may be fragmented with greater ease (Bhatta et al 1989). Struvite stones fragment easily with ESWL, but older struvite calculi can be resistant to the effects of shock waves.

Several investigators have reported their results with different lithotriptors. One of the early reports on the Siemens Lithostar examined the results in 175 patients (Clayman and McClennan 1988). Only 5% required regional or general anaesthesia. The treatment duration averaged 70 minutes and the mean number of shock waves used was over 2800. (Seven thousand shock waves were used in 1 patient.) Eighty-seven per cent of the stones were fragmented, but only 15% had fragments that were less than 2 mm. Seventy patients were followed for more than 3 months. The stone-free rate was only 59%, but 27% of the patients had fragments less than 5 mm. Eleven per cent of the patients had fragments that were greater than 5 mm in diameter and were thought to be significant. The results in over 100 patients treated at the University of Virginia essentially are no different. Patients with 1 cm pelvic calculi are treated with up to 5000 shock waves on the Lithostar.

Another report from West Germany reviewed the results of Lithostar lithotripsy in 4328 patients (Schärfe et al 1988). A stone disintegration rate of 95% was achieved with a mean of 2200 shock waves per patient. Fifty-five per cent of the stones were < 1.5 cm in diameter, while 35% were between 1.5 cm and 2.5 cm in diameter. One treatment was sufficient in 92% of patients. Auxiliary treatments, such as double-pigtail catheter placement, extraction of distal ureteral fragments, or percutaneous procedures, were needed in 14% of patients. Two-thirds of patients were stone free 3 months after discharge, and only 3% had fragments that were too large to pass spontaneously. Subcapsular haematomas were seen in 0.3% of patients and often were associated with uncontrolled hypertension. This incidence and association are similar to those found with the Dornier HM3 lithotriptor (Knapp et al 1988).

Early reports on the Wolf Piezolith from the United States involved few patients. An average of almost 2900 shocks was used for each patient (4000 shock waves in one patient). A 1-month stone-free rate of 73% was achieved, while repeat procedures were needed in 36% of the patients (Preminger & Ewing 1988). It was concluded that multiple treatments would be necessary when treating larger stones on the Wolf Piezolith, but that the retreatment rate would be higher even for an 'average' sized stone.

A more extensive review from Austria examined the results of painless piezoelectric lithotripsy in 438 renoureteral units from 426 patients (Margerger et al 1988). Solitary stones with a diameter less than 1.5 cm were found in 37% of the units, multiple stones of a comparable size in 21% of units, and stones with diameters between 1.6 and 2.5 cm in 21% of units. The remainder had stones with a diameter greater than 2.5 cm. A 97% disintegration rate was achieved, but 39% of the patients required multiple treatments, usually as outpatients. The 3-month stone-free rate ranged from 92% in patients with solitary, smaller (< 1.5 cm diameter) stones to 50% in patients with larger (> 2.5 cm diameter) stones.

The problem with clinical comparisons of different lithotriptors is that the original stones usually have a variable composition. Attempts have been made to compare lithotriptors using synthetic stones composed of chalk or plaster (Schmidt et al 1989). One such study found that more shock waves were required to disintegrate a piece of chalk with a Dornier MPL9000 than with a Dornier HM3. Even more shock waves were required with a piezoelectric lithotriptor.

One of the short-term problems when using an ultrasonically guided lithotriptor is the relative difficulty in localizing calculi. An isolated renal pelvic or caliceal stone in a moderately thin patient offers the optimal conditions for ultrasonic localization. Such stones can be identified and accurately targeted, but once shock wave delivery is initiated, the fragments produced during the initial fragmentation can obscure the remaining core of the stone. The shadowing effects of ultrasonic localization can hide a larger fragment. This can be especially troublesome if a larger fragment is knocked away from the bulk of the stone material. The smaller focal areas associated with the newer lithotriptors, especially the piezoelectric units, make accurate localization and shock wave targeting even more important. The original Dornier HM3 lithotriptor allowed much leeway in placement of the stone at the focus, because the focal area was so large. The very small focal volumes of the piezoelectric machines require extremely accurate targeting of the shock waves. Accomplishing this with an ultrasonic localization system requires much practice and patience.

Ultrasonography has proven very useful for the follow-up examination of patients after ESWL. This practice is especially common in Western Europe where ultrasound equipment is readily available to and usually operated by urologists. Ultrasound is suited ideally for the detection of perinephric haematomas. The presence of residual stone material, hydronephrosis and even sand impacted in the lower ureter (Steinstrasse), also can be determined with non-invasive ultrasonography (Watson et al 1990). In vitro studies have shown that fragments as small as 0.8 mm can be detected with 7.5 MHz transducers (Choyke et al 1989). The practical limit for lower transducer frequencies (3.5 and 5.0 MHz) is 1–2 mm diameter particles.

The comparison of different lithotriptors can be based not only on clinical or experimental efficacy, but also on more basic measures of shock wave characteristics. In Figure 3.12 is shown a pressure tracing from a Wolf Piezolith 2200 and in Figure 3.13 a similar pressure tracing from a Dornier HM3 lithotriptor (Coleman & Saunders 1989). These pressure tracings were obtained with a polyvinylidene fluoride (PVDF) membrane hydrophone placed at the focus of each lithotriptor. Each tracing is characterized by a sharp positive pressure pulse followed by a modest negative pressure pulse.[6] Such pressure tracings can be obtained for each lithotriptor.

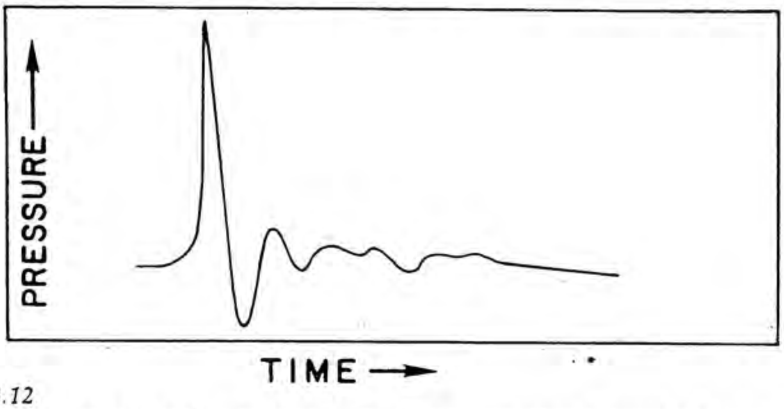

Fig. 3.12

Pressure wave form of a Wolf Piezolith 2200 lithotriptor. (Adapted from Coleman A & Saunders J 1987 Lithotripsy II. BDI Publishing, pp. 121–131.)

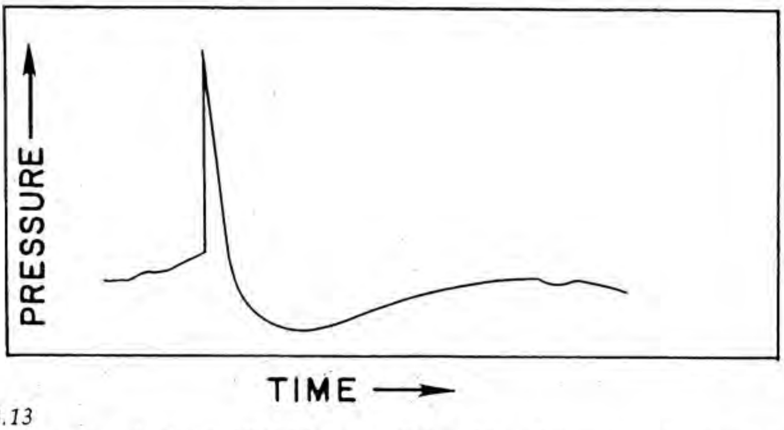

Fig. 3.13

Pressure wave form of a Dornier HM3 lithotriptor. (Adapted from Coleman A & Saunders J 1987 Lithotripsy II. BDI Publishing, pp. 121–131.)

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[6] The negative pressure portion of the shock wave pulse may be responsible for cavitation bubble formation.

It is possible to construct a model standard pressure pulse (Fig. 3.14). By measuring the rise time (T_r), the positive pressure pulse ($p+$), the pulse width at one-half the peak pressure (T_w), and the negative peak pressure ($p-$), it is possible to compare the specifications of different lithotriptors. Electrohydraulic lithotriptors have very short rise times, while the piezoelectric machines have the longest rise times. The piezoelectric lithotriptors have the greatest peak positive pressures.

More extensive measurements of the pressure distribution in two and three dimensions can lead to the construction of diagrams similar to that shown in Figure 3.15 (Hunter et al 1986). These pressure measurements were taken in a plane (XY) that passed through the second focus of a Dornier HM3 lithotriptor and was perpendicular to the major axis of the ellipsoidal reflector. The Z axis in this figure is the pressure measurement. Such two-dimensional pressure plots can be extended to three dimensions to construct the three-dimensional pressure characteristics of the focal volume. It is important to remember that the focal area is not sharply delimited. The focal volume has a fuzzy border. From Figure 3.14 it is clear that the pressure drops uniformly from a very high point within the centre of the focal area to essentially zero pressure some distance away from the focal volume.

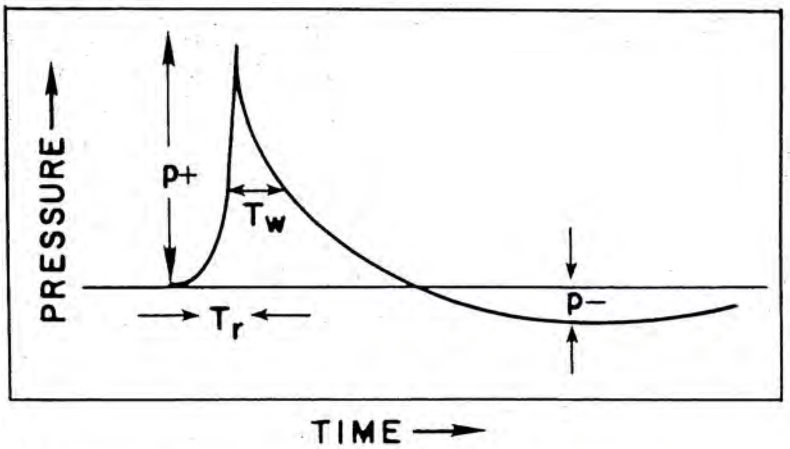

Fig. 3.14

Idealized shock wave with measured parameters that can be used to describe different shock waves and compare different lithotriptors. (Adapted from Coleman A & Saunders J 1987 Lithotripsy II. BDI Publishing, pp. 121–131.)

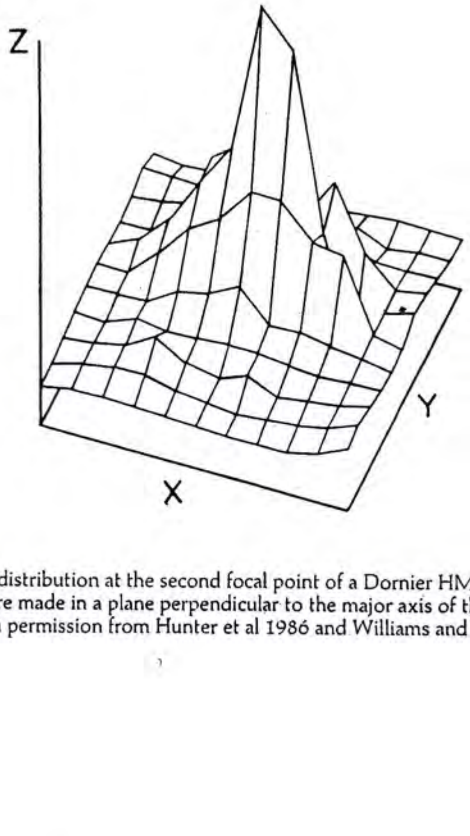

Fig. 3.15

Two dimensional pressure distribution at the second focal point of a Dornier HM3 lithotriptor. The pressure measurements were made in a plane perpendicular to the major axis of the rotational ellipsoid. (Reproduced with permission from Hunter et al 1986 and Williams and Wilkins, publishers.)

The three-dimensional characteristics of the focal volume or region of lithotriptors can be described using Figure 3.16. The focal regions of lithotriptors have a shape similar to a football or cigar. This geometric structure can be described with two numbers, *R* for the longitudinal length and *Z* for the rotational diameter. Such measurements hve been made for electrohydraulic, electromagnetic, and piezoelectric lithotriptors. *R* and *Z* are largest for electrohydraulic lithotriptors and *R* and *Z* are smallest for piezoelectric lithotriptors. The primary determinants of *R* and *Z* are the geometry of the focusing system. The absolute pressure generated is a secondary determinant.

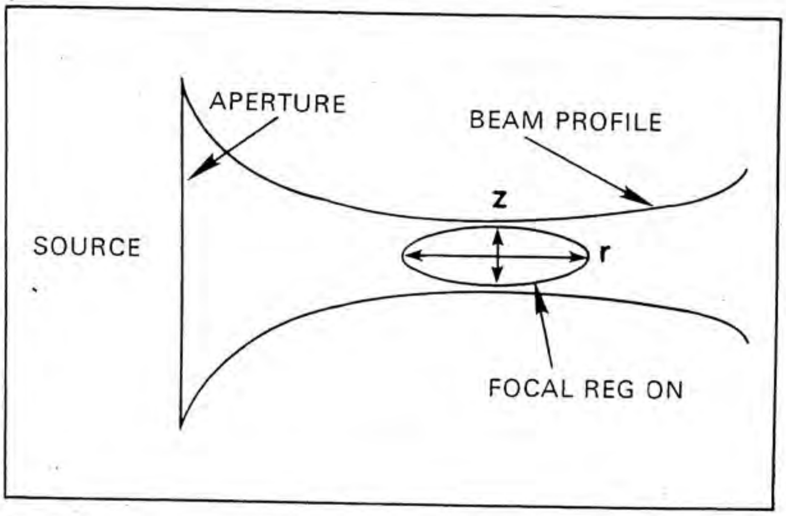

Fig. 3.16

Parameters Z and *R*, that can be used to describe the dimensions of the focal region. (Adapted from Coleman A & Saunders J 1987 Lithotripsy II. BDI Publishing, pp. 121–131.)

The measurements shown in Figure 3.16 can be for a focal volume that is delimited by an absolute pressure or a relative pressure. Most measurements are taken at an isobar that is the 50% positive peak pressure. Schematic examples of such a pressure distribution from three different lithotriptors is shown in the left half of Figure 3.17. The most important factor for determining stone breakup, however, is not the peak pressure, but the existence of a minimum pressure. Since the compressive strength of most stone materials is less than 20 MPa, it is thought that lithotriptors need a minimum of 20 MPa in the focal region to produce adequate fragmentation. If focal volume measurements are made using a 20 MPa isobar, diagrams such as that shown in the right half of the Figure 3.17 are obtained. The upper set of ovals are representative of a piezoelectric lithotriptor that has a very small focal area, but a very high peak pressure. This would lead to a somewhat larger area where the pressure is greater than 20 MPa. The bottom set of ovals are representative of a lithotriptor that generates a large focal area, but a modest peak pressure. The area where the pressure is greater than 20 MPa would be smaller.

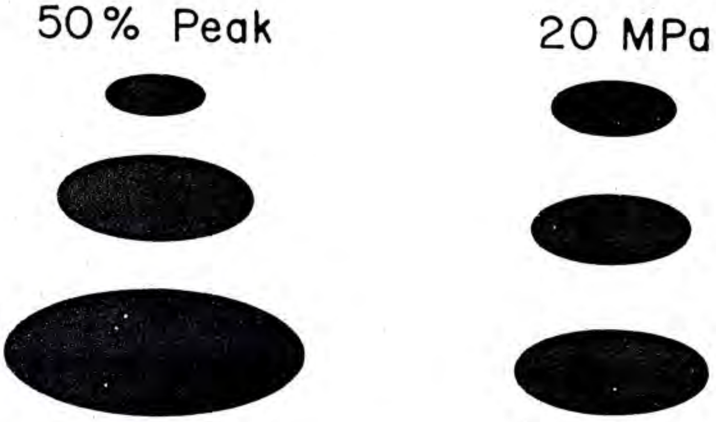

Fig. 3.17

Focal regions of three different lithotriptors (ordinate) as determined by isobars of 50% peak pressure (left half) or 20 MPa (right half).

TREATMENT OF CALYCEAL CALCULI

Before the advent of PCNL and ESWL, surgical removal of isolated calyceal calculi was contemplated rarely. Surgical intervention usually was reserved for those patients with unmanageable symptoms, recurrent urinary tract infections associated with the stone, or patients whose livelihood depended on a stone-free state (airline pilots). The development of percutaneous techniques offered the potential to remove calyceal stones with a greater chance of success and much less morbidity than open surgery. ESWL has further simplified the treatment of these concretions, but enthusiastic acceptance of this new technique has made the clinical significance of calyceal stones even more controversial (Jenkins 1987).

One of the earliest endourological manipulations of calyceal stones was in aircraft pilots who had been declared medically unfit to fly because they had a tiny calyceal stone. Some pilots even requested a nephrectomy so they could resume flying. Some of these patients, however, were treated by dislodging the calyceal stone into the renal pelvis with a guide wire or catheter that had been passed up the ureter and into the stone-containing calyx. The stone then passed spontaneously. The reported success rate with this retrograde manipulative procedure was greater than 70%.

The widespread acceptance of percutaneous endourological techniques led to the percutaneous removal of calyceal stones that were thought to be symptomatic. More often than not, patients would be rendered stone-free (Brannen et al 1986).

The advent of ESWL has made the treatment of such stones even easier. One of the first reports on the use of ESWL in the treatment of calyceal diverticular calculi found that 70% of patients were rendered symptom-free, even though only 20% of the patients had passed all of the stone material (Psihramis & Dretler 1987).

Tightly impacted calyceal stones may be more resistant to ESWL fragmentation for the same reason that impacted ureteral stones may be more resistant. Successive flaking or tearing of layers of stone material at the crystal fluid interface is the proposed mechanism of pulverization. If the surrounding calyceal or ureteral wall prevents the outer shell of stone material from separating from the intact core, subsequent shock waves would be absorbed or refracted by the multiple stone–fluid interfaces. This has been one of the reasons for manipulating ureteral stones back into the renal pelvis. A more pragmatic consideration is that the surrounding tissue may prevent dispersion of the particles, even if satisfactory shattering has occurred. The radiographic appearance of an impacted solid stone and an impacted collection of sand is similar. A several-week observation period may be needed to distinguish between the two conditions. The likelihood of this material passing is greater if it is sand.

It seems reasonable to treat isolated calyceal stones or stones in a calyceal diverticulum if a patient has recurrent urinary tract infections that potentially could be associated with the stone, or if the patient has back or flank pain that lateralizes to the side of the stone. Many patients will have calyceal stones and be 'asymptomatic'. On further questioning, however, it often is possible to elicit a history of flank pain in such patients. As long as the patients understand the potential risks and the benefits expected from ESWL, it is legitimate to treat these small stones (Netto et al 1989).

COMPLICATIONS AND THEIR MANAGEMENT

Patients having had ESWL with Dornier HM3 or Siemens Lithostar lithotriptor often will have a 2–3 cm diameter bruise on their back at the entrance site of the shock waves. Some bruising also may be evident on the anterior abdominal wall, especially in older women with fragile capillaries. Virtually all patients will have gross haematuria for up to 24 hours after the procedure, although only about one-third of patients who have lithotripsy on a Wolf Piezolith will have the gross haematuria that is uniformly seen in patients treated on an HM3 (Preminger & Ewing 1988). Patients with stones in the renal pelvis often will begin to pass sand the evening after treatment. This may be associated with irritative lower tract symptoms as the particles pass through the ureterovesical junction. These irritative symptoms may be confused with urinary retention in older men. The possibility of irritation at the uretero-vesical junction should be considered before passing a urethral catheter in such men.

Patients should have a postoperative radiograph to document the adequacy of stone fragmentation. This radiograph can be taken immediately after treatment or within 24 hours. It also is useful to obtain a follow-up radiograph 1 month after treatment to monitor the passage of the stone material. For all but the most simple stones, it is wise to perform an excretory urogram or ultrasound to make sure that silent obstruction has not developed. Non-function of a kidney several months after lithotripsy has been reported (Hardy & McLeod, 1987). Silent obstruction can develop in some patients and, since they have no pain, they do not seek medical attention. This may occur in very intelligent and well-educated patients. Patients must be reminded to seek medical follow-up, even if they feel fine.

Some patients may develop a column of sand in their ureter. This is a Steinstrasse, which is the German word for stone street. Surprisingly, many of these patients do not have renal colic. A recent review of patients with Steinstrasse filling more than one-third of the length of the ureter found that only 42% had renal colic (Weinerth et al 1989). None with bilateral Steinstrasse had renal colic. Nausea and vomiting occurred in only one-third of the patients. Other signs, such as an elevated serum creatinine, leucocytosis or fever, were the only clues to an obstructed Steinstrasse in one-fourth of the patients.

This lack of colic may be due to the presence of numerous particles that allow urine to percolate through the ureter. A patient with a relatively asymptomatic Steinstrasse can be observed for 2–4 weeks. If the sand does not pass within this period of time, or if the patient has an acutely symptomatic Steinstrasse, two techniques can be used to solve the problem. Patients can be cystoscoped and a ureteral catheter can be placed in the orifice. The application of pulsed water irrigation with a syringe or a water-pik device will flush many of the particles loose (Fig. 3.18) (Rubenstein & Norris 1988). Usually it is dangerous to attempt to pass a ureteral catheter, or even a guidewire, because resistance to passage through this sand often will be greater than the resistance to passage of the wire through the ureteral wall.

Some patients may be obstructed because a large leading fragment prevents passage of the more proximal, finer sand. This large fragment can be removed ureteroscopically or fragmented with the pulsed dye laser, electrohydraulic probe, or ultrasonic wand. In some situations it is possible to pulverize a large leading fragment with in situ ESWL.

Usually it is best not to remove all of the material ureteroscopically. Vigorous efforts to remove all of the sand may severely injure the ureteral mucosa and lead to a stricture.

A safer approach to the treatment of Steinstrasse is to place a percutaneous nephrostomy. Patients often will begin to pass material after the nephrostomy tube has been placed. This may be related to more efficient ureteral peristalsis and coaptation of the ureteral walls after the hydroureteronephrosis has resolved. One study reported spontaneous fragment passage in almost three-quarters of the patients after a nephrostomy tube was placed (Weinerth et al 1989). Antegrade pulsed water irrigation (Fig. 3.19) also can be used to loosen the fragments, especially if they do not pass spontaneously (Selby et al 1987). Antegrade pulsed water irrigation should not be used if a large leading fragment is the cause of the distal obstruction.

Although the problem of Steinstrasse can be solved, it is best to prevent this by placing a double-pigtail catheter (Libby et al 1988). These catheters seem to be most useful in patients with a moderately large stone burden (greater than 1.5–2 cm mean stone diameter).

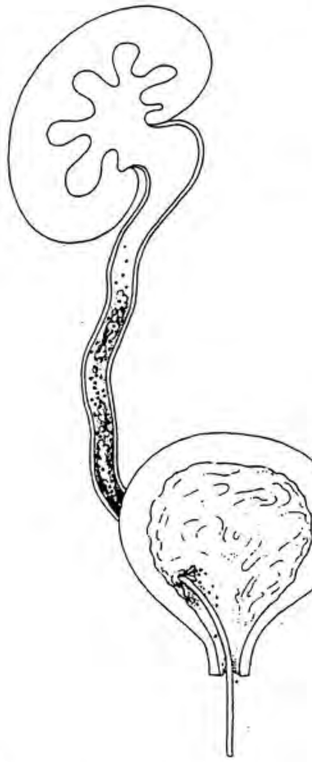

Fig. 3.18

Retrograde pulsed water irrigation of a lower ureteral Steinstrasse. A 5 French angiographic catheter is passed through a cystoscope, negotiated into the ureteral orifice, and moved up the ureter while using pulsed water irrigation. This permits dislodgement of the fragments without perforating the ureter. (Reproduced with permission from Jenkins 1990.)

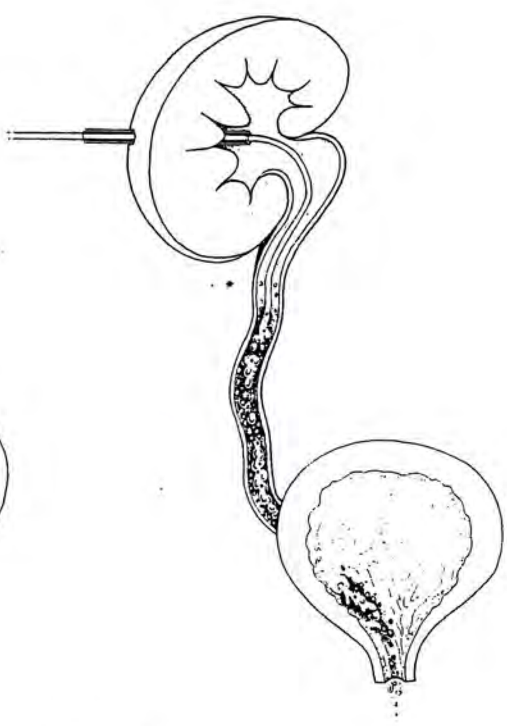

Fig. 3.19

Antegrade pulsed water irrigation of a lower ureteral Steinstrasse. The 5 French angiographic catheter has been passed through a 12 or 14 French Amplatz sheath that has been placed percutaneously. (Adapted from Tegtmeyer et al 1986, with permission from the Radiological Society of North America.)

The low probability of developing an obstructive Steinstrasse with stones smaller than 1.5–2 cm does not seem to merit the prophylactic placement of a double-pigtail catheter (Pryor & Jenkins 1990, Preminger et al 1989). The irritative lower tract symptoms associated with the catheters can be very aggravating. Removal of the double-pigtail catheter after treatment can be expedited if a monofilament suture is attached to the end of the catheter and permitted to exit from the urethra. Patients can remove the catheters themselves 3–4 days after treatment.

Some stent manufacturers have attached a metal tip to the bladder end of a double-pigtail catheter and used a magnetic retriever to remove these catheters without cystoscopy. The removal of such stents is relatively straightforward in women, but can be very difficult, if not impossible, in men. The need for such stents seems to have been obviated by the use of attached sutures or the use of flexible cystoscopy to remove the stents.

ADVERSE EFFECTS

Many patients will complain of nausea and vomiting after ESWL (Lingeman et al 1988). This problem may be related to a small amount of retroperitoneal bleeding that occurs with ESWL or possible small erosions in the gastrointestinal tract that have been reported in a few patients after ESWL (Al-Karawi et al 1988). The nausea usually resolves within 24–48 hours, although patients may have a reduced appetite for a week or two.

The most significant complication following ESWL is the development of a perinephric haematoma (Knapp et al 1988). This occurs in less than 1% of patients who have ESWL. A retrospective study found that the likelihood of developing a haematoma did not correlate with the voltage (up to 24 kV) or the number of shock waves (up to 2000).[7] The likelihood of developing a haematoma was higher in those patients with hypertension, especially those with unsatisfactory control of their elevated blood pressure.

Patients with a clinically significant perinephric or subcapsular haematoma may complain of severe flank pain after they have recovered from the anaesthetic. Although the initial assumption is that the pain is due to renal colic from obstruction by stone fragments, urologists must always be suspicious of the development of a significant haematoma. This possibility can be evaluated with a renal sonogram. Most patients who have a symptomatic haematoma will not require blood transfusion or renal exploration.
Nevertheless, there have been reports of a need for post-ESWL arterial embolization, late surgical drainage of a haematoma that did not resolve spontaneously, and even nephrectomy.

The adverse effects of three basic lithotriptor designs were evaluated in a more scientific fashion by Drs Clayman and Preminger and their colleagues (Clayman et al 1989). These investigators examined the in vitro effects of shock waves produced by a Dornier HM3, a Siemens Lithostar, and a Wolf Piezolith on a human renal cancer cell line (TK-10). Each machine was operated at its maximally accepted clinical level (2400, 6000, and 4000 shock waves for the HM3, Lithostar and Piezolith respectively) and at twice that level. The Lithostar seemed to have the least adverse effect on viability, 24-hour plating efficiency and growth rate. The Dornier HM3 lithotriptor had the greatest effect on these parameters. The effects of the Piezolith were between those of the Lithostar and the HM3.

A potentially more significant complication is the development of hypertension after ESWL. Two initial reports, one from Indiana and one from Florida, reported an 8% incidence of new onset hypertension after ESWL (Lingeman et al 1988, Williams et al 1988). Preliminary data from a retrospective study of almost 1000 patients treated at the Methodist Hospital in Indianapolis found no difference between the incidence of new onset hypertension in patients who had ESWL and those who had percutaneous stone treatment (Lingeman et al 1989). Other, uncontrolled, studies found that the incidence of new onset hypertension after ESWL was no greater than that which might be expected in a comparable group of individuals selected from the general population.

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[7] An original Dornier HM3 lithotriptor was used to treat these patients.

In summary, many experimental studies have shown that ESWL causes acute changes within the kidney, and the severity of the injury appears to be related to the number and strength of the shock waves. The vast majority of these acute changes resolve. Further study will be needed to resolve the long-term effects on renal function, stone recurrence and possible adverse systemic effects, such as hypertension.

FUTURE DEVELOPMENTS

The initial reports of extracorporeal shock wave lithotripsy were greeted with almost uniform scepticism, even by respected urologists. Now, well over 90% of urinary tract calculi can be managed with ESWL, including stones in the kidney and the entire ureter. The success of the Dornier HM3 lithotriptor prompted many investigators to develop newer machines. Although the ultimate portable lithotriptor that can justifiably be purchased by every urologist and has no associated adverse effects has yet to be developed, the multiple approaches to lithotripsy that have developed in one decade make the possibility of an inexpensive portable lithotriptor not unrealistic.

Third generation lithotriptors that have integrated fluoroscopy and ultrasonography recently have become available (Dornier Kompakt-lithotriptor, Siemens Lithostar Plus, Wolf Piezolith 2500, Storz Modulith and Diasonics). These new machines are more commonly available in Europe.

What does the future hold? Figure 3.20 is an illustration from the United States Patent assigned to Siemens in 1985 (Hassler et al 1985). Shock waves are generated by an ultrasonic transducer that consists of a mosaic piezoelectric element (1). The array is focused electronically. The location and depth of the focus can be changed electronically (2). The piezoelectric array that generates the shock waves also allows ultrasonic visualization of the stone. Not only can the returning echoes be observed visually (4), but the arriving echo spectrum can be analysed electronically. This evaluation of the returning echoes may provide a more accurate endpoint for final stone pulverization. Such a device has yet to be developed commercially, but it may become a reality before the next century.

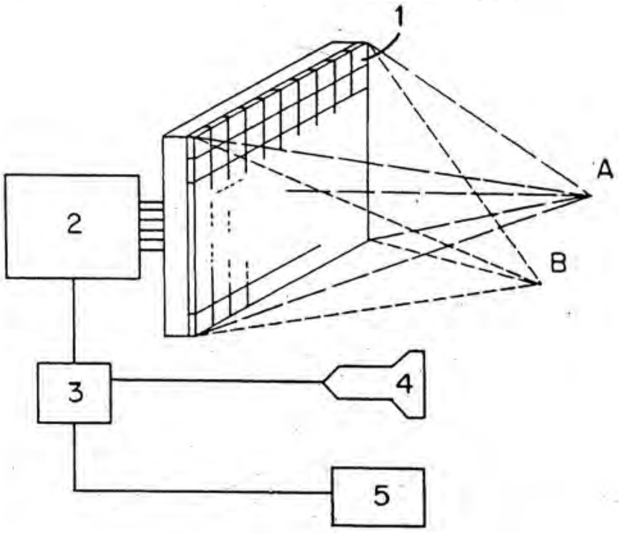

Fig. 3.20

Sketch of a lithotriptor design in the United States patent issued to Siemens. This flexible machine offers the potential of automatic operation. (Reproduced with permission from Jenkins A D 1987 1990 Urology Annual. Appleton and Lange, East Norwalk C T, pp. 266–273.)

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Chapter 4

Extracorporeal shock wave treatment of ureteral stones

A D Jenkins

Introduction

When the Dornier HM3 lithotriptor was approved for general clinical use by the United States Food and Drug Administration in 1984, only stones in the kidney and upper ureter above the iliac crest could be treated. Chaussy and his colleagues initially treated ureteral stones in situ and reported a success rate no greater than 50% (Chaussy et al 1981). Several patients had open surgical removal of the fragments. Most of the stones had been disintegrated, but the pieces were held together by oedematous mucosa. This phenomenon was seen mainly in patients who had stones that caused complete ureteral obstruction for more than 6 weeks.

This observation led Chaussy to select only those patients who had a relatively short history of ureterolithiasis for primary ESWL treatment. The remaining patients had cystoscopy and passage of a ureteral catheter in an attempt to negotiate the ureteral stones back to the collecting system. If the stone could not be moved with a ureteral catheter, then a ureteroscope was inserted and an attempt was made to push the stone more proximally with the ureteroscope, or to retrieve the stone primarily. With this approach, the success of the initial treatment was between 75% and 95% (Chaussy & Schmiedt 1983).

Subsequently the decision was made to pass catheters in all patients with ureteral stones. An attempt would be made to push the stone back to the collecting system. If this was not possible, an attempt was made to pass a 4 French stent around the stone. It was thought that this additional space would lead to more successful disintegration. Successful disintegration could be achieved in over 90% of the patients and a 3-month stone-free rate of 98% was achievable.

ASSESSMENT OF FRAGMENTATION

One of the most troublesome aspects of ESWL is determining the adequacy of fragmentation. How many shock waves are enough? One of the best indications is dispersion of the sand, but this can occur only if the stone is located in a larger cavity, such as the renal pelvis. Calyceal or ureteral stones may be pulverized satisfactorily after 1500 shock waves, but the radiographic appearance may appear unchanged. Should such stones be treated with an additional 500 or 1000 shock waves?

Impacted ureteral stones at the University of Virginia usually are treated with 2500–3000 shock waves at 24–28 kV (using an original Dornier HM3 lithotriptor) (Barr et al 1990). The discomfort and risk associated with a second ESWL treatment within 24 hours outweighs the hypothetical danger of treating the ureter with 3000 shock waves during a single session.

Even if the 24-hour post-treatment plain radiograph shows no definite pulverization, the patient should be followed for a couple of weeks before considering re-treatment. Oedematous ureteral mucosa may prevent dispersion of the sand. Resolution of the oedema will permit the fragments to pass. This approach should be used only if the patient remains afebrile and relatively asymptomatic.

EXPANSION SPACE THEORY

The presumed action of shock waves on a stone is the creation of interacting compressive and tensile forces at fluid–stone interfaces. Stone material is torn off in layers. Clinically, impacted ureteral stones appear to be more resistant to shock wave fragmentation than are stones lying in a capacious renal pelvis. One explanation for this observation is that the initial shock waves remove an outer layer of stone material, but the surrounding ureteral walls do not allow these particles to fall away (Fig. 4.1) (Mueller et al 1986). The multiple new fluid–stone interfaces interfere with the transmission of the next series of shock waves to the core of the stone, thereby preventing complete fragmentation. Many urologists believe that the efficiency of ureteral stone fragmentation can be increased by pushing the stone back into the kidney with a ureteral catheter, or by providing an expansion space within the ureter. The stone depicted in Figure 4.2 is impacted and has no natural expansion space. The stone illustrated in Figure 4.3, however, has a natural expansion space. Theoretically, the stone in Figure 4.3 will respond better than the stone in Figure 4.2 to in situ ESWL. There is no advantage to negotiating such a stone back to the renal pelvis with a ureteral catheter, because the initial stone particles can disperse in the dilated ureter.

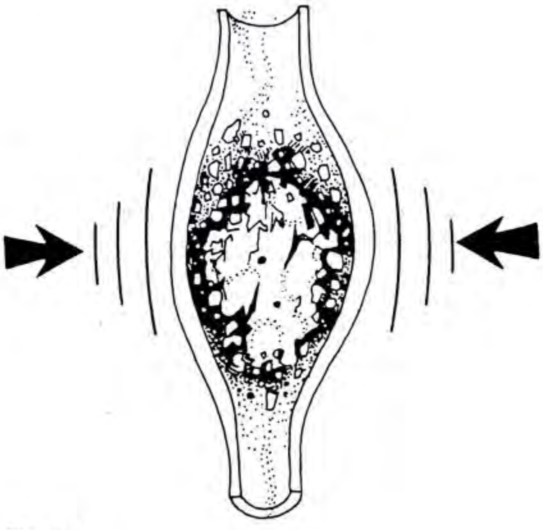

Fig. 4.1

Illustration of a partially fragmented, impacted ureteral stone. The outer layer of fragments create multiple fluid–stone interfaces that will absorb the energy of subsequent shock waves, thereby preventing fragmentation of the solid core. (Adapted from Mueller et al 1986 with permission of authors and Williams and Wilkins, publishers.)

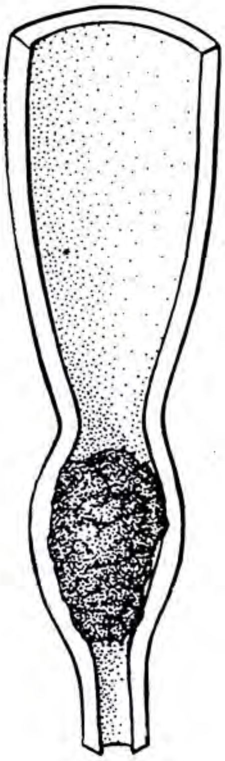

Fig. 4.2

Impacted ureteral stone with no expansion space. Theoretically, such a stone will respond poorly to in situ ESWL. (Reproduced with permission from Jenkins 1988.)

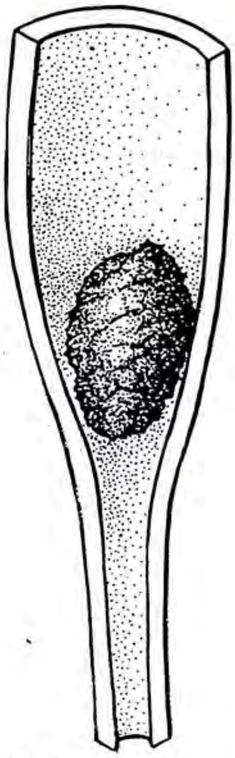

Fig. 4.3

Ureteral stone with a natural expansion space. Theoretically, such a stone will respond well to in situ ESWL. (Reproduced with permission from Jenkins 1988.)

The expansion space theory says that the stone in Figure 4.2 cannot be treated satisfactorily with in situ ESWL, because the initial layer of fragments would prevent further fragmentation by subsequent shock waves, as shown in Figure 4.1. This situation can be remedied by pushing such a stone back to the kidney with a ureteral catheter or ureteroscope, by bypassing the stone with a ureteral catheter to provide an artificial expansion space, or by irrigating the stone during in situ ESWL (Fig. 4.4) (Griffith 1987) to flush the particles away from the solid stone core. The only disadvantage to ureteral irrigation is that renal pelvic pressure may increase enough to result in a forniceal tear and extravasation. This probably would not have any adverse affects if the patient had sterile urine.

The expansion space theory is very appealing, but there is very little evidence to support its validity. One study has attempted to answer this question experimentally (Mueller et al 1986). These investigators used artificial stones (composed of brushite, phenylsalicylate and magnesium stearate). They placed these tablet-like stones in Penrose drains or gelatin tubes. There was no attempt to quantitate the degree of fragmentation, but qualitatively there appeared to be slightly more fragmentation if the Penrose drain was not stretched tightly around the stone or if the stone was not enclosed in gelatin. No attempts have been made to repeat this interesting study.

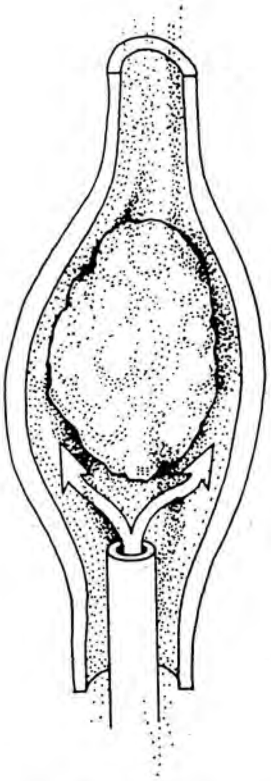

Fig. 4.4

Creation of an artificial expansion space by injecting fluid through a ureteral catheter whose tip has been placed just distal to a stone. This creates an expansion space as well as flushing the newly fragmented stone particles away from the solid stone core. (Reproduced with permission from Griffith 1987.)

There is an alternative explanation for the clinical impression that impacted ureteral stones are more difficult to fragment with ESWL. It may be that ureteral stones that can be pushed easily back to the kidney with a ureteral catheter would fragment easily in situ, while those stones that cannot be negotiated back to the kidney would be difficult to fracture in situ. The passage of a ureteral catheter and the negotiation of a stone back to the kidney would simply select those stones that would have broken easily with in situ ESWL.

URETERAL CATHETERIZATION

One of the major problems when treating ureteral calculi with a Dornier HM3 lithotriptor is that the oblique angles of the two fluoroscopic systems and the adjacent vertebral bodies and transverse processes may make localization of a ureteral stone difficult (Fuchs et al 1987). If a patient is placed in a flat, supine position in the bathtub, the ureteral stone often will be superimposed on a transverse process or vertebral body. This is true especially for stones near the 5th lumbar vertebra (Fig. 4.5). This situation can be remedied, in part, by rotating the patient to move the stone off the spine (Fig. 4.6). Unfortunately, this does not always work.

The potential difficulty in accurately localizing a ureteral stone is the most practical reason for passing a ureteral catheter. If the stone flips back into the renal pelvis, then the treatment can proceed as with a pelvic stone. If the stone cannot be moved back to the kidney, then the ureteral catheter can be left in place and used as a guide during fluoroscopic localization.

Most urologists attempt to pass a catheter, usually under fluoroscopic control, before treating a ureteral stone with ESWL. Some urologists favour pigtail-type ureteral catheters, while others favour the combination of a small diameter (6 F), flexible ureteral dilator and a Bentson-type guidewire. The extremely floppy tip of the guidewire prevents inadvertent perforation of the ureteral wall. If a stiffer catheter is desired, then the guidewire can be pulled back into the dilator. If it is not possible to push the stone back to the kidney, then it may be possible to negotiate the guidewire and ureteral dilator past the stone. If the stone is highly impacted, then it may be helpful to use one of the newer guidewires that have a hydrophilic coating and are very slippery. Once the dilator has been passed to the kidney, then a stiffer guidewire and a double-pigtail catheter can be placed if the urologist wants to provide temporary drainage.

If the stone does not move back easily to the kidney with simple ureteral catheterization, then irrigation through the catheter can be tried. The most widely used irrigant is a mixture of 2% water-soluble xylocaine jelly mixed with normal saline or distilled water (Lupu et al 1986). Usually the mixture is 20–30% jelly and 80% or 70% saline or water. Five to 10 cc of solution are injected and repeated attempts are made to disimpact the ureteral stone.

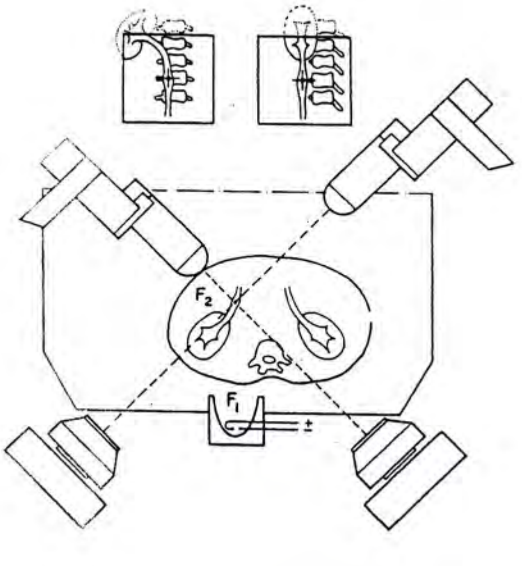

Fig. 4.5

Superimposition of a ureteral stone over a vertebral body and a transverse process. (Reproduced with permission from Fuchs et al 1987.)

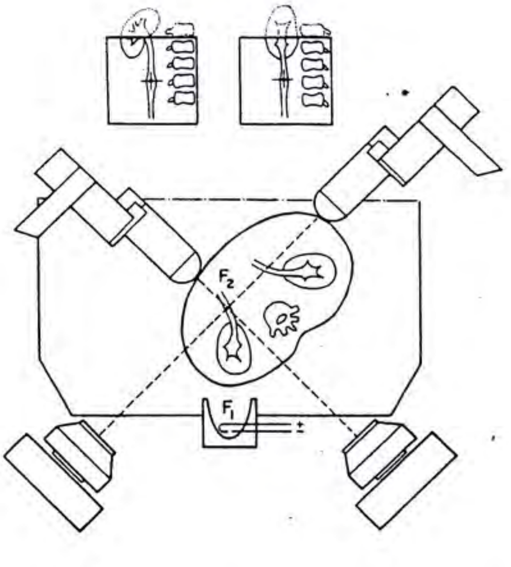

Fig. 4.6

In some patients the superimposition of a ureteral stone over the spine can be corrected by rotating the patient. Unfortunately, this is not uniformly successful. (Reproduced with permission from Fuchs et al 1987.)

The ability of three different solutions to aid the manipulation of ureteral stones back to the kidney was examined in a randomized fashion at the University of Virginia (Evans et al 1988). None of the stones (mean diameter 10 mm) could be dislodged with simple ureteral catheterization. The success rate following saline injection was 76%, while that for a dilute lidocaine jelly was 60%, and for dilute plain surgical lubricant was only 48%. Although it appears that the saline was a better irrigant, no statistically significant difference could be found. Pressure injection of carbon dioxide has been used to push ureteral stones back into the kidney before antegrade percutaneous extraction (Hulbert et al 1985). All these patients had a percutaneous nephrostomy that provided a pressure relief mechanism. Extensive extravasation of carbon dioxide can occur if a system for relieving the pressure is not provided.[7]

Ureteral perforation should be avoided, especially proximal to an obstructing stone. Urinary extravasation will occur invariably if the patient remains obstructed or becomes obstructed distal to the perforation. If no distal obstruction is present, such perforations usually heal spontaneously, because the flap of ureteral mucosa that occurs with the perforation will tend to seal spontaneously with the antegrade flow of urine. If ureteral perforation does occur and is recognized, then it is safest to place a double-pigtail catheter for a few days.

Patients with ureteral calculi often have severe symptomatic obstruction. Even if the stone is pulverized in situ, residual fragments and ureteral oedema may prevent relief of the obstruction. If a guidewire can be advanced to the kidney, it may be possible to place a double-pigtail catheter. This should relieve the obstruction and render the patient relatively asymptomatic, except for the bladder irritation associated with the catheter. The catheter can be removed if passage of all of the sand is documented after ESWL. Removal of the pigtail catheter can be accomplished by the patient if a pull-out suture is attached to the bladder end of the catheter and left dangling from the urethral meatus.

Drainage of the kidney is necessary in some patients who have severe colic or sepsis, but retrograde passage of a catheter may be impossible. A temporary percutaneous nephrostomy should be placed immediately. This may be life-saving in septic patients, and symptomatic patients will be grateful for relief of the pain.

If there is any doubt about the adequacy of fragmentation immediately after ESWL, the patient should be observed for 2 or 3 weeks before administering a second treatment (Jenkins 1988). If residual stone material is still apparent, then stone manipulation should be repeated. This will be easier if a double-pigtail catheter has been left in place, because such catheters tend to dilate the ureter. It may be possible to remove the fragments ureteroscopically.

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[7] Although carbon dioxide is relatively safe, it is not readily available. There is a strong temptation to use air, which can be very dangerous if large amounts are injected intravascularly.

CHOICE OF TREATMENT

The advent of shock wave lithotripsy has slightly modified the terms used to describe the different ureteral segments (Fig. 4.7). The upper ureter lies between the ureteropelvic junction and the upper border of the iliac crest. It is generally accepted that stones in the upper ureter can be treated with ESWL. The lower ureter is that portion between the upper border of the iliac crest and the ureterovesical junction. ESWL was not approved initially for the treatment of stones in the lower ureter, but since the introduction of the HM3 lithotriptor, many investigators have successfully treated stones throughout the lower ureter. It is helpful if the lower ureter is further divided into a presacral portion and a juxtavesicular portion. The presacral portion is that segment which lies entirely over the sacroiliac joint. The juxtavesicular ureter is that portion between the lower border of the sacroiliac joint and the ureterovesical junction. This division is entirely pragmatic. It determines the position in which patients are treated.

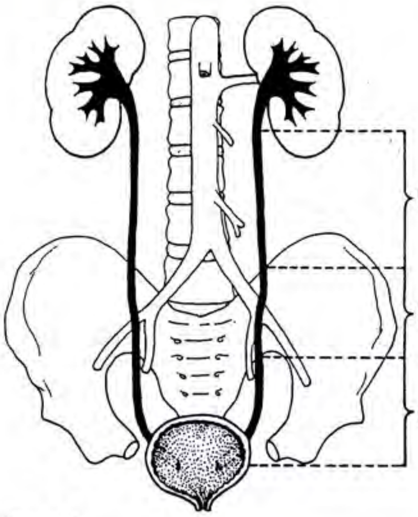

Fig. 4.7

A practical anatomical division of the ureter. The advent of ureteroscopy and extracorporeal shock wave lithotripsy makes this scheme more practical than that used when ureterolithotomy and blind manipulation were the primary options for treating ureteral stones. (Reproduced with permission from Jenkins 1990.)

UPPER URETERAL CALCULI

Gentle retrograde manipulation of an upper ureteral stone usually is attempted before ESWL. This is done almost uniformly when using a lithotriptor, such as an original HM3, that requires a formal anaesthetic. The advent of lithotriptors that require less or no anaesthesia has made the passage of a ureteral catheter less routine, but even in this situation patients can be cystoscoped and ureteral catheters can be passed quite easily using local anaesthesia. In situ treatment of ureteral calculi is practical only for lithotriptors with fluoroscopic localization. For practical purposes, ultrasound cannot localize stones in the ureter, except for stones that are close to the ureteropelvic junction or the ureterovesical junction (Marberger et al 1988).

If a catheter is passed, but it is not possible to negotiate the stone back to the kidney, then the catheter should be left adjacent to the stone to aid localization. Shock wave lithotripsy proceeds as with renal calculi, but patient positioning in the chair may be more difficult. The catheter usually can be removed immediately after treatment.

Of 66 primary upper ureteral calculi treated with ESWL at the New York Hospital Cornell Medical Center, 22 were manipulated to the kidney and 5 were manipulated to a more proximal position within the ureter (Riehle & Naslung 1987). In situ ESWL was used for 39 stones that could not be moved. The mean stone diameter was approximately 10 mm in all groups. The manipulated stones received a mean of 1200 shocks, while the stones treated in situ received a mean of 1400 shocks. The 3-month stone-free rate for the manipulated stones was 93% and that for the in situ stones was 85%. The authors concluded that shock wave lithotripsy of upper ureteral stones was significantly more successful than ureteroscopy.

Investigators from the Methodist Hospital of Indiana reviewed 471 treatments in 465 patients with solitary ureteral calculi (Lingeman et al 1987). More than 85% were manipulated into the kidney. The energy required for pulverization and the need for subsequent procedures (repeat ESWL or endoscopic manipulation) were less in those patients who had successful manipulation. The 3-month success rate, defined as the absence of residual stone material or the presence of clinically insignificant fragments, was higher in those patients with successful manipulation (99%). The success rate in those patients who had in situ ESWL without any pre-ESWL manipulation was 87%. These authors concluded that ESWL is the treatment of choice for upper ureteral calculi, because it is more likely to be successful than ureteroscopy and is less morbid than antegrade percutaneous extraction.

LOWER URETERAL CALCULI

The Dornier HM3 lithotriptor has not received official approval from the Food and Drug Administration for the treatment of stones in the ureter below the iliac crest. Nevertheless, several investigators have treated these stones successfully, not only with the HM3, but with newer lithotriptors (Pettersson & Tiselius 1988). These early studies reveal that different approaches were needed for ESWL of stones in the juxtavesicular ureter and those in the presacral ureter.

PRESACRAL URETERAL CALCULI

The initial University of Virginia experience with in situ ESWL of lower ureteral calculi included 10 patients who were treated in the standard supine position. Six patients had a juxtavesicular stone, while 4 patients had presacral ureteral calculi. No fragmentation was observed in 3 of the 4 patients with presacral calculi (Jenkins et al 1985). Subsequent patients with presacral ureteral calculi were treated in the prone position.

Supine ESWL of presacral calculi usually is futile for two reasons. First, bone is not injured by shock waves, but it blocks transmission of the shock wave energy. Second, the anterior position of presacral ureteral stones hinders exact placement of the stone at the second focal point, because the working distance between the top of the ellipsoidal reflector and the second focal area of the HM3 lithotriptor is 13 cm (Fig. 4.8) (Hunter et al 1986). The distance between a presacral stone and a patient's back usually is greater than 13 cm, while the distance between a stone and the patient's anterior abdominal wall usually is less than 13 cm.

Both of these problems can be solved by turning the patient over. Prone positioning permits precise placement of a presacral ureteral stone at the second focus and unobstructed shock wave transmission.

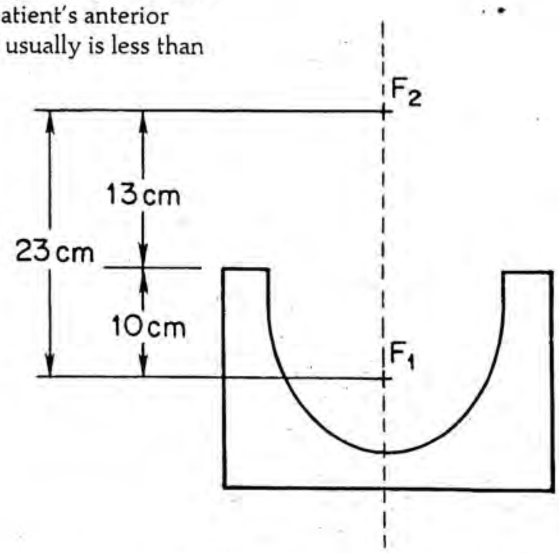

Fig. 4.8

Schematic of the ellipsoidal reflector in the original Dornier HM3 lithotriptor. The distance between the second focal point and the top of the reflector is fixed at 13 cm. This limitation exists for many lithotriptors. (Reproduced with permission from Jenkins A D and Gillenwater J Y 1988 *Controversies on the Management of Urinary Stones.* S Karger AG, Basel, p. 129.)

Prone treatment on an original HM3 lithotriptor with a non-motorized gantry requires a technical modification (Jenkins & Gillenwater 1988). The original HM3 patient gantry consists of a subassembly for supporting the patient's head and back and a subassembly for supporting the legs. The leg subassembly, headrest and armrests are removed. One-half of an old Stryker frame is attached to the backrest and transverse leg bridge. The patient is rolled onto the Stryker frame, after adequate epidural anaesthesia has been established, and treatment proceeds as with standard supine ESWL (Fig. 4.9). As with all ureteral calculi, pretreatment ureteral catheterization will expedite fluoroscopic localization.

The records of 11 patients who had prone ESWL of presacral ureteral calculi at the University of Virginia were reviewed. One patient had an ileal conduit urinary diversion 12 years before her admission. Her lower tract was reconstructed 10 years later, but within 2 years stones had formed in her bladder, along the staple line of the ileal nipple and in the right ureter at the level of the ureterointestinal anastomosis. All but the ureteral stone were ultrasonically pulverized under direct vision. The ureteroscope could not be passed into the right ureter. Prone ESWL was chosen instead of percutaneous extraction or ureterolithotomy. The ureteral stone was pulverized with 2000 shock waves.

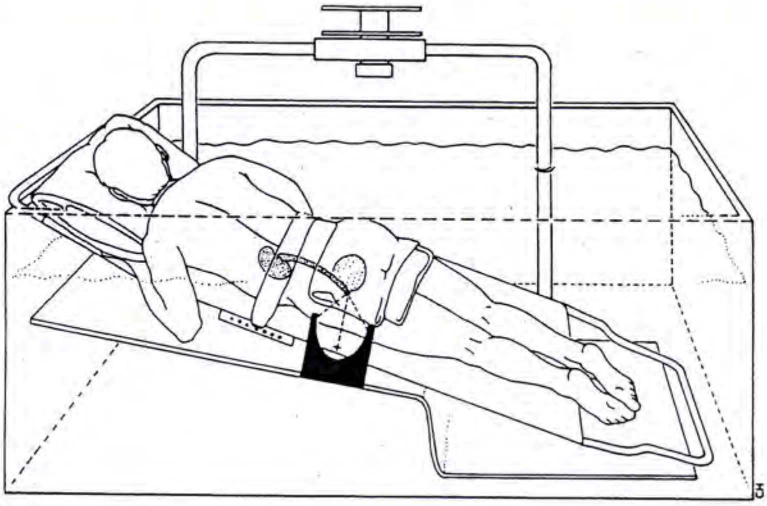

Fig. 4.9

Schematic of a patient undergoing prone ESWL for a presacral calculus. The non-motorized patient chair on the Dornier HM3 lithotriptor has been modified with a Stryker frame. (Reproduced with permission from Jenkins and Gillenwater 1988 and the publishers Williams and Wilkins, Baltimore.)

Eight of 9 patients with normal anatomy had an unsuccessful attempt at ureteroscopic manipulation, but ureteral catheters were placed adjacent to the stone. A large prostate prevented ureteral catheterization in a 10th patient. Most stones were treated with 3000 shock waves at 24–30 kV.

Excellent pulverization was achieved in all patients with a single prone ESWL treatment. One patient required a percutaneous nephrostomy after ureteroscopic extraction failed, but he readily passed all of the sand after prone ESWL. Another patient required a temporary percutaneous nephrostomy and cystoscopic manipulation of the impacted fragments.

All patients had the expected gross haematuria after ESWL, but this resolved within 24 hours. Most patients had a small erythematous area at the shock wave entrance site, but no patient had melaena. All patients were stone-free at 1 month.

Although modification of the gantry is required with the original HM3 lithotriptor, patients can be placed prone on the newer motorized gantry provided with the HM3 lithotriptor without any modification (Puppo et al 1988, Miller et al 1988). The flat table-top lithotriptors, such as the Siemens Lithostar, also expedite the prone treatment of patients. The vast majority of lithotriptors, however, have a fixed focal distance.

JUXTAVESICULAR URETERAL CALCULI

The standard treatment for lower ureteral calculi in the United States is ureteroscopy and extraction or lithotripsy (electrohydraulic, ultrasonic, or pulsed dye laser) (Blute et al 1988, Politis and Griffith, 1987). The initial experience with in situ ESWL of lower ureteral calculi at the University of Virginia was limited to patients in whom ureteroscopy had been unsuccessful. More recently, it is offered as an initial procedure if retrograde access to the ureter is impeded by a large prostate, or if the patient does not want to undergo instrumentation. Preliminary passage of a catheter assists localization during treatment and rarely may move a lower ureteral stone into the upper ureter or renal pelvis.

The HM3 patient chair is not modified, but an extra set of straps is placed between the back rest and thigh rests to prevent the patient from falling through the chair. The patient is placed in a more cephalad, sitting position so that shock waves can be directed through the left or right buttock (Fig. 4.10) (Miller et al 1986).

The records of the first 36 patients who had in situ ESWL of a single juxtavesicular ureteral stone at the University of Virginia were reviewed. A mean of 2200 shock waves at a mean of 24 kV were delivered during a single treatment session to stones whose mean diameter was approximately 9 mm. The mean length of hospitalization was slightly more than 2 days, but 5 patients required readmission. Eight patients needed additional post-ESWL procedures: repeat ESWL (4 patients), ureteroscopic extraction of fragments (5 patients), or temporary percutaneous nephrostomy (1 patient). After ESWL at the University of Virginia, 1 patient had 2 ureteroscopic procedures, a ureterolithotomy, and a ureteroneocystostomy, all at another institution.

Three months after ESWL, 23 patients had no residual stone material and a normal excretory urogram, 2 patients had residual non-obstructing stone material, and 4 patients refused further radiographs because they were asymptomatic. The 1 patient who had a ureterolithotomy was stone-free. No follow-up information was available in 6 patients.

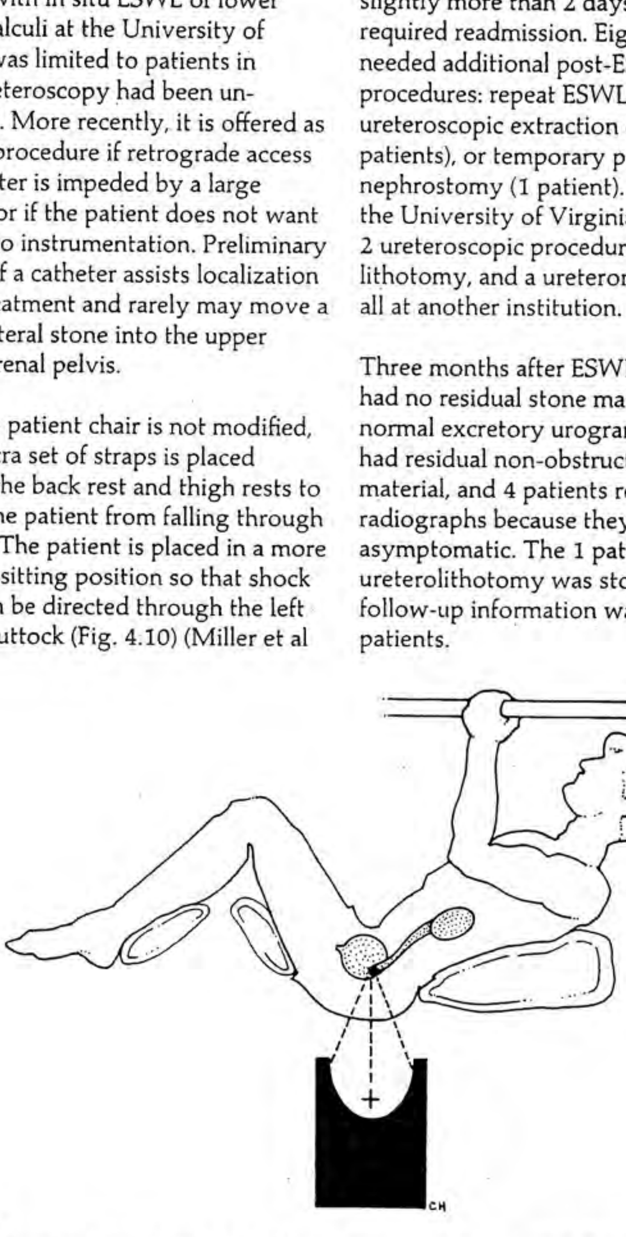

Fig. 4.10

Treatment of a juxtavesicular stone in an HM3 lithotriptor with the patient in the sitting position. (Reproduced with permission from Jenkins 1990.)

Cole and Shuttleworth (1988) reported on in situ ESWL of lower ureteral stones in 40 patients. All but one stone were in the juxtavesicular ureter, and an unmodified Dornier HM3 lithotriptor was used for all treatments. Thirty-three of the stones had a diameter ⩾ 8 mm, while only one stone was smaller than 5 mm. Satisfactory disintegration was achieved with one treatment in 90% of patients. The mean number of shocks given to each patient was 1728 (range 400–3000), and the range of generator voltage was 22–24 kV. Of the patients followed for at least 3 months (34), 79% were stone free. One-half of the remaining 6 patients, at 1 month, had residual fragments smaller than 2 mm.

Rassweiler and associates have had a similar experience with ESWL for distal ureteral calculi (Rassweiler et al 1986). Sixteen per cent of 25 patients required ureteroscopic fragment removal after ESWL, but no patient needed a second ESWL treatment. A mean of 1750 shock waves was delivered to each stone. These physicians do not perform any pre-ESWL manipulation and place the patient in a flat position on the chair.

The successful use of in situ ESWL for the treatment of lower ureteral stones led other investigators to use newer lithotriptors for distal ureteral stones. Treatment of lower ureteral calculi is surprisingly easy with the Siemens Lithostar (Schärfe et al 1988). The angled shock heads can be placed on a patient's buttock. The shock waves are directed through the sacroiliac window. Such patients can be treated without ureteral catheterization. Although the treatment can be accomplished without any anaesthesia, patients are more comfortable with minimal intravenous sedation.

Eight such patients have been treated at the University of Virginia with a TENS unit and minimal intravenous sedation. Only 1 patient required cystoscopic extraction of a large fragment 3 weeks after the ESWL treatment. The remaining patients were rendered stone-free with ESWL alone.

The treatment of juxtavesicular stones by ureteroscopy or ESWL was compared by El-Faqih et al (1988) in Saudi Arabia. The major part of the stone was extracted ureteroscopically (one or two sessions) in 97% of 65 patients. Successful stone fragmentation by in situ ESWL was achieved in 94% of 53 patients. Localizing ureteral catheters or guidewires were used in 19% of the ESWL patients. Two ESWL patients required a post-ESWL supplemental procedure: 1 had a transurethral evacuation of the residual stone fragments from a large ureterocele, and the other an open resection of a ureteral stricture that was just distal to the fragments. The stone-free rate in the ureteroscopy group was 93%, while that in the ESWL group was 90%. Successful distal ureteroscopy was associated with a ureteral injury in 4 patients. Two of these patients developed a severe stricture at the site of the injury and subsequently required a ureteroneocystostomy with a Boari flap. These authors thought that ESWL should be the primary method of intervention in patients with distal ureteral calculi.

COMPLICATIONS

The complications of ESWL of ureteral calculi appear to be related primarily to the manipulative procedures that are done before or after ESWL. There are no reports of adverse affects associated with in situ ESWL of ureteral calculi alone. The one patient who had in situ ESWL of a distal ureteral stone at the University of Virginia, who subsequently required a ureteral reimplantation, had two ureteroscopic procedures and a ureterolithotomy, all of which were performed at another institution after the patient left the University of Virginia.

A potential concern exists regarding possible adverse effects on ovarian function and fertility when young women with lower ureteral stones are treated with in situ ESWL. The effects of ESWL on the rat ovary and fetus were examined by Dr McCullough and his colleagues at the Bowman Gray School of Medicine (McCullough et al 1988). Female rats of reproductive age had a left oophorectomy. The remaining rats were then divided into control rats, sham treated rats, and rats who received 1500 shock waves at 15 kV to the remaining right ovary. The Dornier experimental lithotriptor, XL1, was used to treat the animals. The shock waves appeared to have no effect on fertility, or on the number of, or the morphology of, fetuses produced by shocked rats. The rat ovary appeared to be resistant to the shock waves, at least those produced by the Dornier XL1 lithotriptor. There have been no clinical reports of adverse effects on reproductive and endocrine function in women who have had in situ ESWL of lower ureteral calculi.

SUMMARY

Most experts think that ESWL is the preferred method for treating calculi in the upper ureter (Lingeman et al 1986). ESWL appears to be safer and at least as, if not more, effective than ureteroscopic manipulation or percutaneous antegrade manipulation.

The treatment of calculi in the lower ureter has been controversial. Most North American urologists favour ureteroscopic manipulation. Small stones can be extracted whole, while larger stones can be fragmented with ultrasonic, electrohydraulic, or pulsed dye laser lithotripsy. The success in treating lower ureteral stones in situ with the Dornier HM3 lithotriptor and the subsequent introduction of lithotriptors that require less or no anaesthesia has encouraged some urologists to abandon ureteroscopic treatment of lower ureteral calculi in favour of in situ ESWL. In situ ESWL of lower ureteral calculi seems to be more common in Western Europe than in North America, but there are a few urological centres in North America that preferentially will treat lower ureteral calculi with ESWL alone. The spread of newer lithotriptors will make in situ treatment of lower ureteral stones even more common.

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Chapter 5

Percutaneous stone manipulation

M Marberger

Introduction

As early as 1941 Rupel and Brown removed small renal calculi with a cystoscope through a nephrostomy tract established at open surgery. As tracts of this type are usually curved and enter the collecting system at positions unfavourable for reaching calculi, the applicability of this method remained restricted to anecdotal cases (Engelking & Albrecht 1969, Brantley & Shirley 1974, Bissada et al 1974, Harris et al 1975). Although Goodwin et al had already described a technique for percutaneous nephrostomy providing a straight tract to the kidney in 1955, it was not until two decades later that Fernström combined the two methods, leading to a systematic approach for removing kidney stones without the need for open surgery (Fernström & Johannson 1976). He thus became the father of a new field of urological surgery, which within the following five years became an integral part of routine renal surgery. Important steps in this development were the introduction of simple commercially available nephrostomy sets (Günther et al 1979, Barbaric 1979), the use of sonography for puncture guidance (Pedersen et al 1976, Stables & Johnson 1979), the applicability of ultrasonic (Kurth et al 1977) and electrohydraulic (Raney 1975) lithotripsy for stone disintegration within the kidney, the development of the purpose-built universal nephroscope with continuous flow irrigation (Marberger et al 1981, 1982), rapid tract dilatation systems (Alken 1981, Rusnak et al 1982, Clayman et al 1983b) and the development of one-stage nephrolithotripsy (Wickham & Miller 1983).

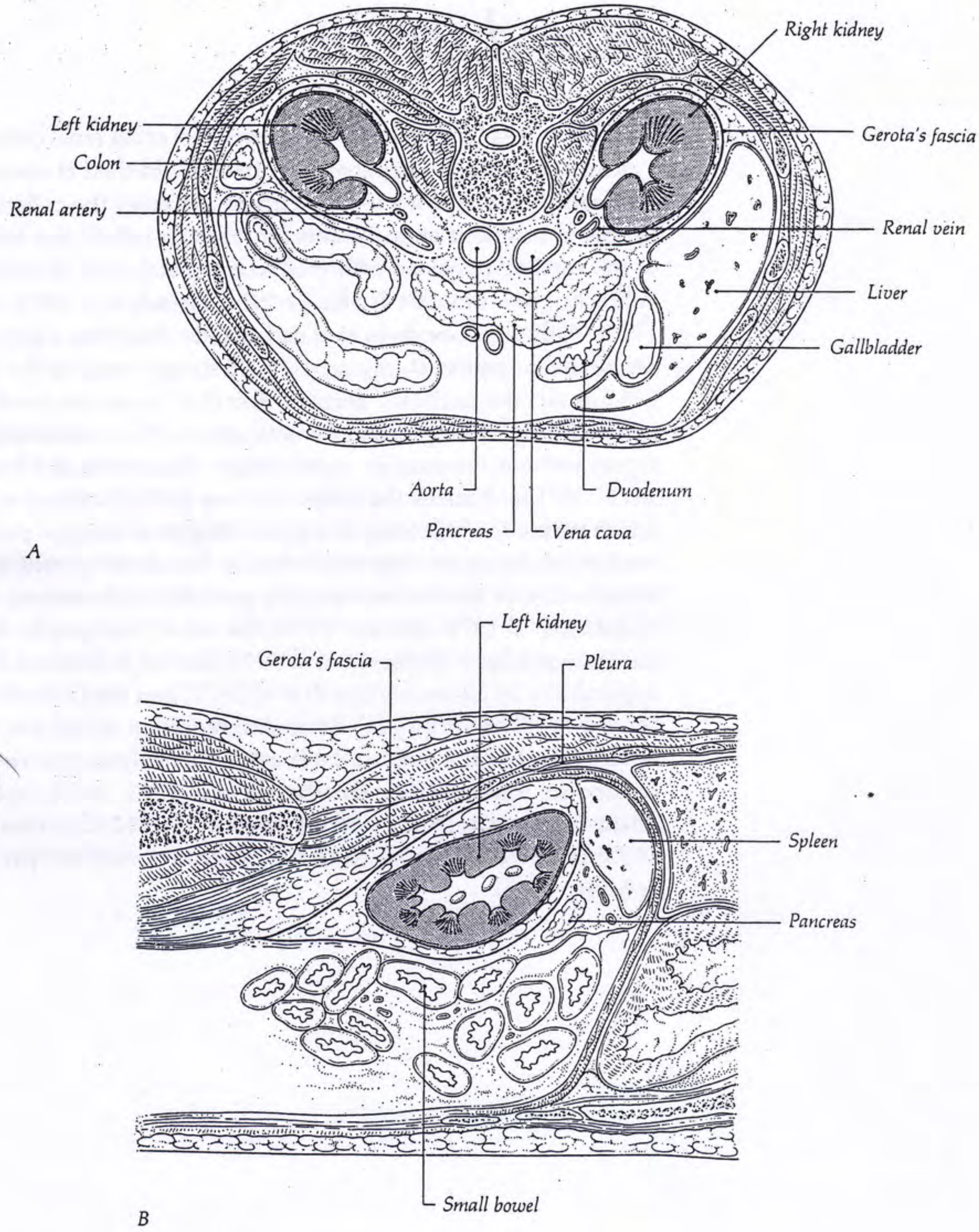
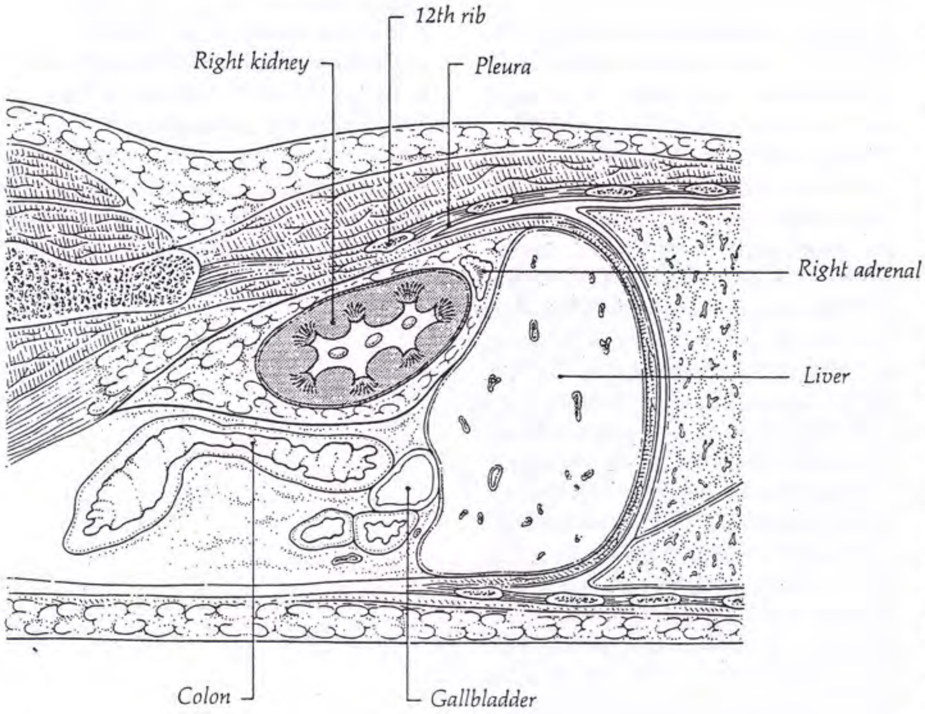


Fig. 5.1

Schematic drawing of the perirenal topography: transverse section through the mid portion of both kidneys (*A*), parasagittal sections through the left (*B*) and right kidney (*C*), with the patient in the prone position; axial computerized tomography, transverse section (*D*), in patient with pelviceal stone in mobile left kidney—note length of nephrostomy tract needed and proximity of colon.



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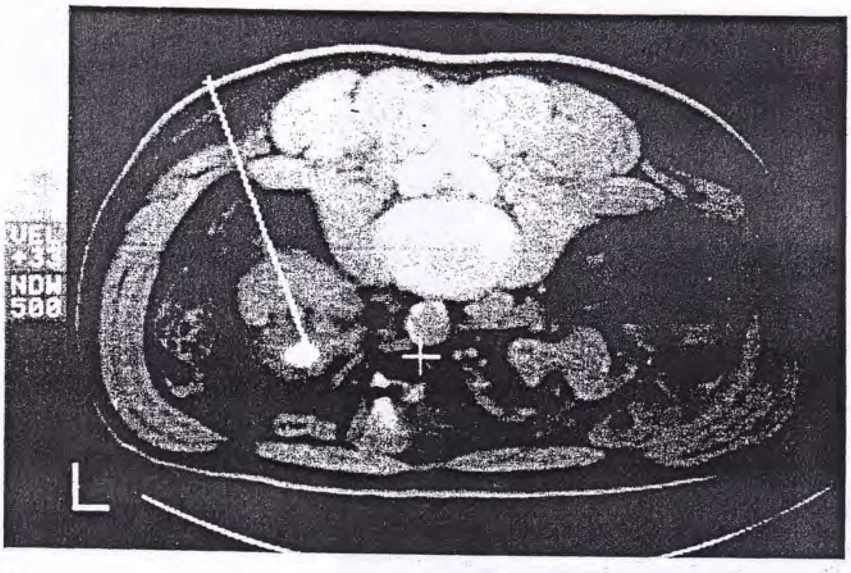

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ANATOMICAL CONSIDERATIONS

Under normal conditions the posterior and lateral margins of both kidneys lie immediately subjacent to the lateral abdominal wall, respectively psoas major and quadratus lumborum muscles and the arcuate ligaments (Fig. 5.1). A transparenchymal puncture of the renal collecting system from a posterolateral approach therefore only transverses the structures of the abdominal wall, the posterior leaf of Gerota's fascia, the perirenal fat, the fibrous capsule of the kidney and the renal parenchyma. With the exception of the pleura in the posterior costodiaphragmatic recess, which overlaps the superior pole of the kidney, and the colon, which is in close contact with the medial, anterior aspect of the kidneys, there are no adjacent organs liable to be injured. Although on transverse and sagittal cross-sections the pancreas, spleen, liver and adrenal glands are shown to be in close proximity to the kidney (Fig. 5.1), they are never interposed between the posterior aspect of the kidney and the abdominal wall. In a series of more than 2500 patients subjected to percutaneous nephrostomy we never experienced an injury of these organs, and only once a lesion of an aberrant bile duct (Hruby 1987).

The lower line of the pleura usually crosses the 12th rib at the lateral border of the erector spinae, so that the part of the 12th rib posterior to this point lies above the line of the pleura. If the puncture is performed at a point below the 12th rib and approximately two-finger breadths lateral to the lateral border of the erector spinae, i.e. approximately along the posterior axillary line, pleural lesions are reliably avoided. With a supracostal puncture there is, of course a high chance of opening the pleura and causing a pneumo- or hydrothorax and even urinary extravasation into the chest (Fig. 5.2).

The relation of the 12th rib to the collecting system shows considerable individual variation and is influenced by the respiratory movement of the organ and its mobility. Wickham and Miller (1983) investigated the position of the various calyces in relation to the 12th rib on excretory urograms taken at maximum expiration with the patient supine: 80% of the lower pole calyces of the right kidneys were positioned below the 12th rib, but only 42% of the middle and 20% of the upper calyces. The left kidney was usually slightly higher, with 78% of the lower pole calyces, 30% of the middle and only 15% of the upper pole calyces in a subcostal position. In females the middle calyces on the right were slightly lower than in males. The figures clearly demonstrate that a lower pole calyx will be the routine port of entry into the collecting system unless specific problems, such as a stone in an upper pole calyx inaccessible by any other approach, justify the higher risk of a supracostal puncture.

The position of the colon is easily defined by sonography, which is routinely performed immediately prior to the puncture for delineating the direction of the optimum tract. Problems only occur with extremely mobile kidneys, which with the patient in the prone position may drop medially to the colon (see Fig. 5.1D).

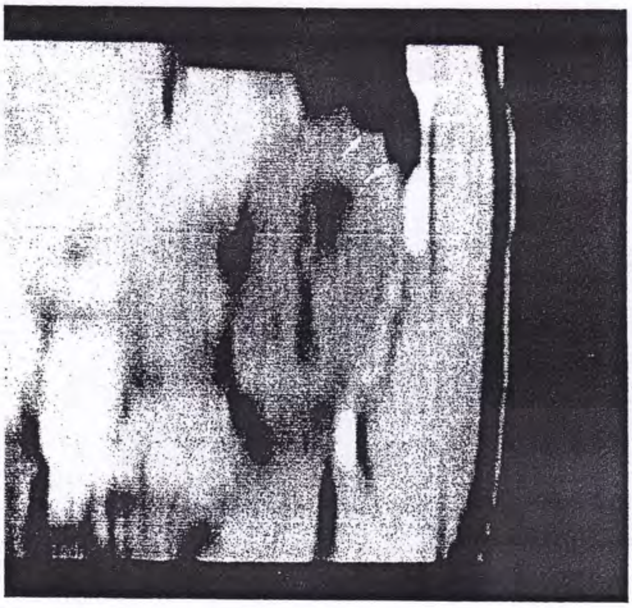


Fig. 5.2

Coronal reconstruction of computed tomography of the left kidney, showing the pleural cavity interposed between abdominal wall and upper pole of the kidney (arrows).

In the classic type of kidney with a true renal pelvis, the anterior and posterior calyces are arranged to the coronal plane of the kidney in angles of 70° and 20° (Kaye 1983). On a standard intravenous urogram the anterior calyces will therefore appear as the lateral extensions of the collecting system with the typical cup-like structures, whereas the posterior calyces will be in an orthotopic projection due to the overlying pelvis (Fig. 5.3). The posterior calyces are more easily identified from lateral oblique views or by sonography from a lateral oblique view. The latter technique also delineates the position of the pleura and the colon. Computed tomography, of course, is unsurpassed in showing the morphological details of the kidney, stone and perirenal structures in difficult pathological situations (Fig. 5.4).

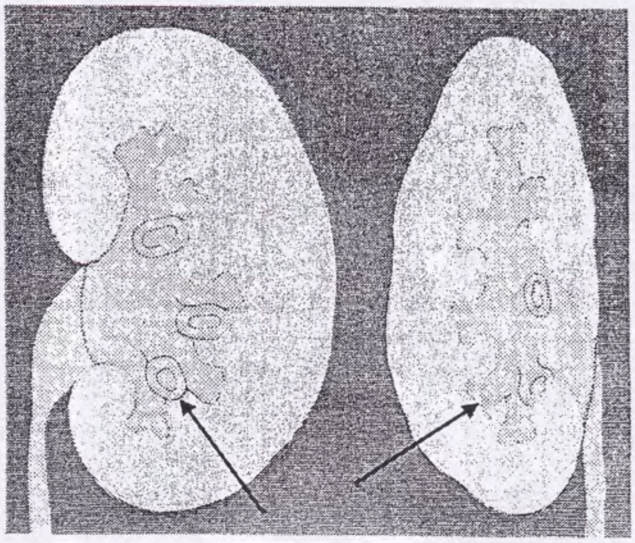
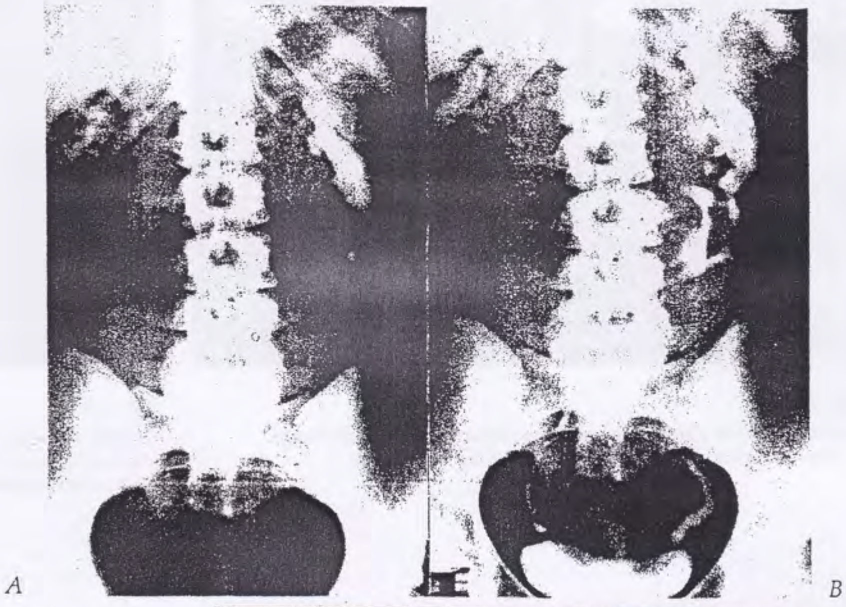


Fig. 5.3

Schematic drawing of appearance of the posterior lower calyx (arrow) at excretory urography in the standard anterior-posterior projection and in a lateral one-third oblique projection.



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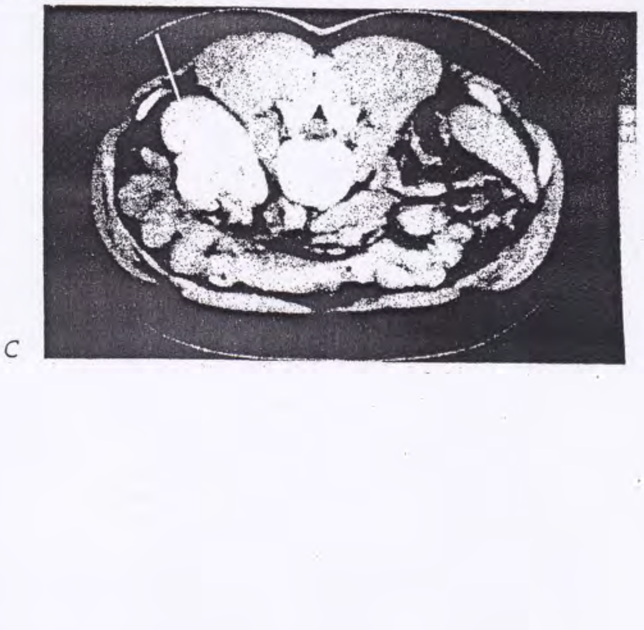

Fig. 5.4

Fused crossed dystopia of the kidneys with staghorn stone in the upper (left) moiety: plain film (*A*) and excretory urogram (*B*). Axial computerized tomography (*C*) demonstrates the anterior position of the stone-bearing collecting system and renal vasculature and delineates the ideal calyx for percutaneous access to the stone (arrow).

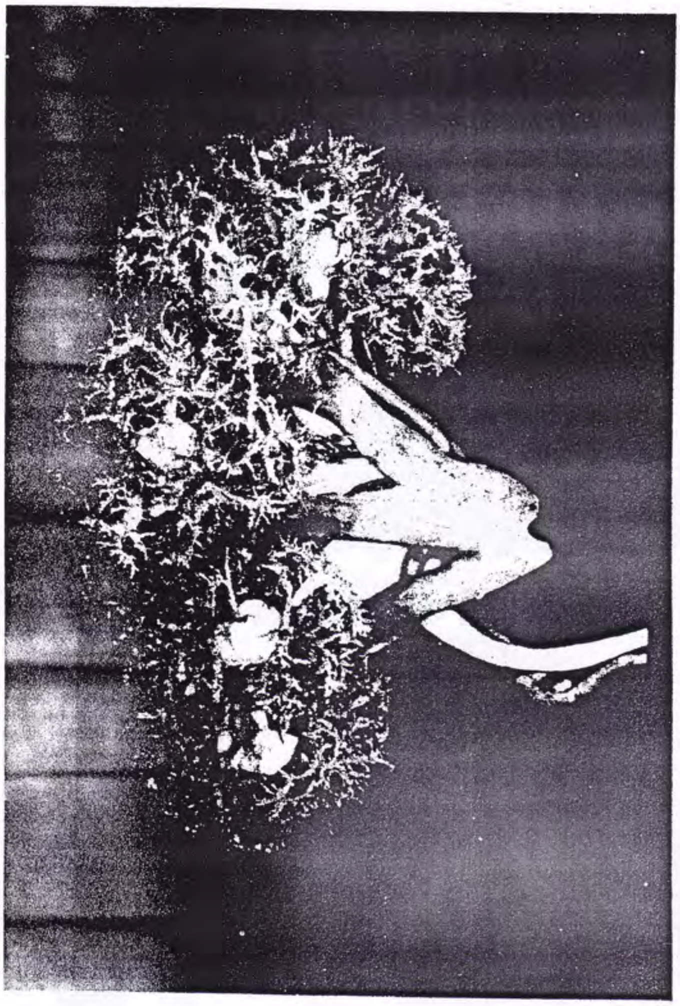

Fig. 5.5

Corrosion cast of a right human kidney, anterior aspect; note large venous tributaries immediately anterior to the renal pelvis.

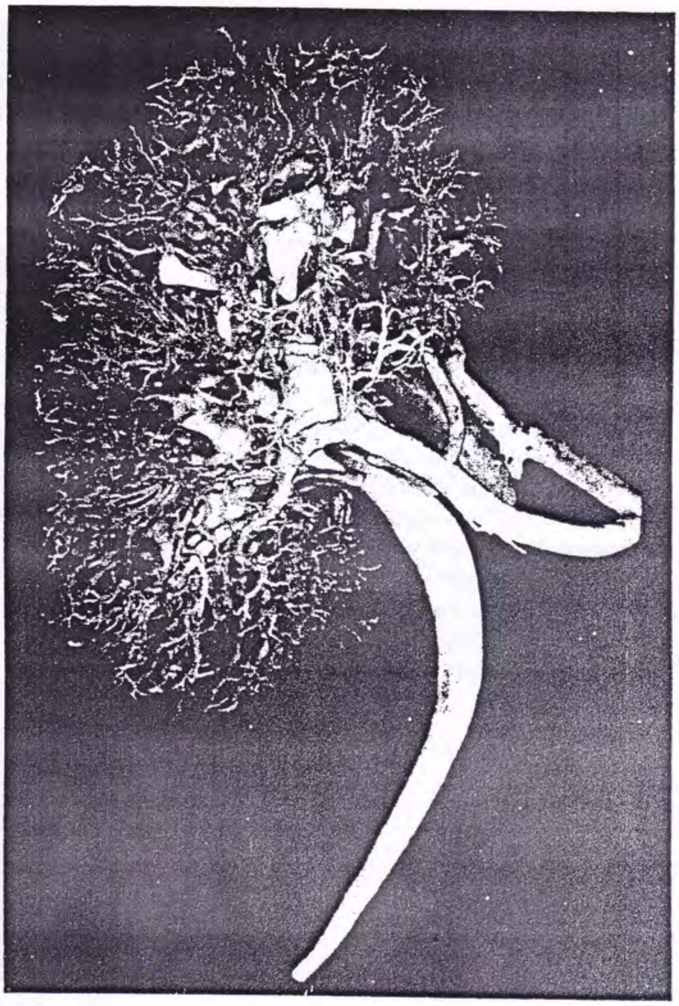

Fig. 5.6

Corrosion cast of a left human kidney, posterior aspect; note posterior segmental artery crossing behind the renal pelvis (the peripheral veins were removed with an air brush).

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The renal artery and vein and most of their major branches are anterior to the renal pelvis and therefore almost opposite to the point of entry into the kidney. Once the collecting system is punctured and the needle is not advanced further, there is little risk of damaging larger vessels (Fig. 5.5). The posterior segmental artery feeding the posterior segment between the apical and basilar segments of the kidney, lies posterior to the pelvis but usually crosses it at the level of the upper pole infundibulum and then courses downwards parallel to the hilar rim (Fig. 5.6). It crosses the direction of the nephrostomy tract and may be injured if the kidney is punctured too medially. The lower pole segmental artery supplies the basilar segment either with one major vessel anterior to the pelvis or anterior and posterior branches on both sides. They tend to be close to the lower pole infundibulum and may also be traumatized when the collecting system is punctured too medially, or the needle is advanced too far anteriorly (Fig. 5.7).

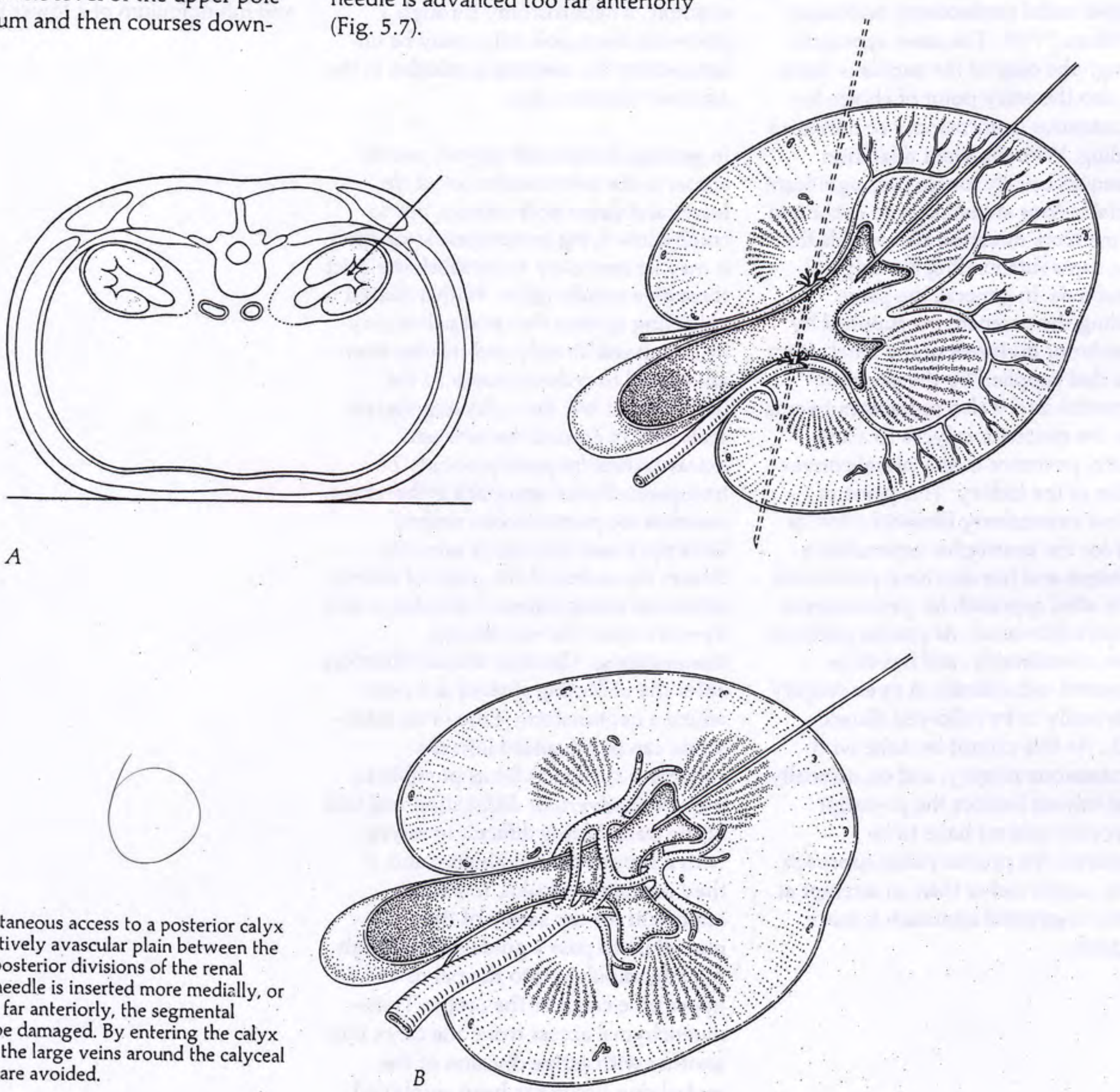

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Fig. 5.7

Correct percutaneous access to a posterior calyx (*A*) in the relatively avascular plain between the anterior and posterior divisions of the renal artery; if the needle is inserted more medially, or advanced too far anteriorly, the segmental arteries may be damaged. By entering the calyx at its cusp (*B*) the large veins around the calyceal infundibulum are avoided.

The arterial supply of the kidney is arranged segmentally, with no collaterals between major vessels. The distribution of the various segments varies greatly (Boyce et al 1979) but within the peripheral cortex the feeding interlobular arteries run in a strictly radial direction along the columns of Bertini. When approaching the papilla as peripherally as possible directly from the convexity of the kidney major arteries are rarely encountered and this approach has been used widely for the multiple radial nephrotomy technique (Wickham 1979). The same approach through the cusp of the papilla is therefore also the entry point of choice for percutaneous nephrostomy to minimize bleeding. With the blunt dilatation techniques usually employed, significant arterial lesions are unlikely to occur and this puncture direction also avoids the large veins surrounding the calyceal infundibula. In general, the plane dividing the parenchyma supplied by the anterior divisions of the renal artery from that supplied by the posterior segmental artery also projects outwards from the posterior calyces to a line slightly posterior to the lateral convex border of the kidney. This plane of relative avascularity (Broedel's line) is used for the anatrophic nephrotomy technique and has also been postulated as the ideal approach for percutaneous puncture. However, its precise position varies considerably, and has to be delineated individually in open surgery, if it is really to be followed (Boyce 1983). As this cannot be done with percutaneous surgery, and occasionally other calyces besides the posterior lower pole calyces have to be punctured, the precise radial approach to the papilla rather than an attempt at an intersegmental approach is more practical.

The success of percutaneous nephrolithotripsy depends entirely on the correct position of the percutaneous nephrostomy. All calculi must be reached through this tract and, when rigid endoscopes are used, it must be straight. The position of the calculus and the topography of the collecting system therefore ultimately decide the correct puncture site and this must be precisely delineated preoperatively. This is particularly important for peripheral calyceal calculi, as, for example, a nephrostomy through a posterior lower pole calyx may be unsatisfactory for reaching a calculus in the adjacent anterior calyx.

In general, lower pole calyces permit access to the pelvis and most of the lower and upper pole calyces, but to reach a low-lying ureteropelvic junction it may be necessary to establish the tract through a middle calyx. With a dilated collecting system the renal pelvis may be punctured directly and this has been advocated to reduce trauma to the parenchyma, but the collecting system seals poorly around the tube and extravasation frequently occurs. The transparenchymal approach is therefore essential for percutaneous nephrolithotripsy and the tract is safer the thicker the cortex at the point of access. Intrarenal manipulation is also facilitated by more space for endoscopic manoeuvring. The tract should therefore enter the collecting system at a point where a nephrostomy tube or an endoscope can be advanced into the collecting system as far as possible to prevent inadvertent dislocation and loss of the tract. This is difficult in calyces with a stenosed infundibulum and, if they contain a calculus, it is most important for the safety of the procedure to pass a guidewire through the infundibulum into the pelvis and an upper pole calyx or the ureter. Transparenchymal access from one calyx into another with active division of the underlying tissue has been employed successfully in selected cases (Wickham & Miller 1983), but carries a considerable risk of haemorrhage and should be restricted to the hands of the experienced intrarenal surgeon.

In summary, the nephrostomy tract for percutaneous stone manipulation must be individualized to the specific situation, but it should always be performed via a transparenchymal approach as straight to the stone as possible, preferably through the papilla and infundibulum of a lower pole calyx.

SURGICAL STRATEGY

Percutaneous nephrolithotripsy is a multiphase procedure which can be subdivided into the establishment of the nephrostomy tract, tract dilatation and stone manipulation itself. The steps can be performed in one session, or staged. With the latter approach a percutaneous nephrostomy is usually placed under local anaesthesia as a first step and the tract is dilated and the stone removed in a second step at a later time in local or general anaesthesia. Puncturing the collecting system causes some, albeit usually minor, haemorrhage, which may blur vision during endoscopic manipulation if performed immediately thereafter. Inexperienced endourologists may therefore find it simpler and safer to perform the endoscopic part of the procedure 24 hours after the nephrostomy tract has been established. This also offers the advantage that contrast dye injected for delineating the collecting system at the time of puncture has disappeared at the time of stone manipulation, so that residual dye cannot be mistaken for residual stones on control films. Most important, however, is a logistic advantage of the staged approach when the radiologist and urologist co-operate with the procedure. Both can work independent of each other's schedule and use optimum facilities. The radiologist will usually place the nephrostomy in the angiography suite, with minimum radiation exposure because of the under-table tube. The urologist prefers urological X-ray units with overhead tubes, which provide sufficient space for sterile manipulation over the patient and give better spot-film techniques, or the C-arm. These units are quite unpopular with radiologists because of high scatter radiation. Splitting the procedure not only permits better timing and use of the various facilities, but also splits the radiation exposure between the two physicians.

The disadvantages of the staged approach are obvious. The patient is subjected to two separate procedures, which add up in anxiety, discomfort and hospitalization. More important, every nephrostomy tube carries an inherent risk of tube dislocation and improper drainage, which correlates directly to the time it remains in place, the mobility of the patient and the kidney, the shape of the collecting system and the position of the tube within the kidney. Although some of these factors can be influenced, tube problems more than neutralize the advantages of better vision and less contrast dye. At least in the hands of the experienced endourologist, the success rates of one- and two-stage procedures are today virtually identical (see Table 5.2). Single-stage interventions, of course, are more popular with the patients and this factor has become even more important with the introduction of ESWL. Currently, we routinely perform all percutaneous manipulations as one-stage procedures, unless exceptionally large stones, haemorrhage, or other unexpected complications require staging.

The percutaneous insertion of a nephrostomy tube has become a routine procedure in everyday urology. In most instances, however, the nephrostomy tract is established for draining purposes, i.e. a tube of adequate calibre is inserted somewhere into the collecting system in a position secure enough to achieve this goal. The situation is more complex with nephrolithotripsy:

1. The tube has to be placed precisely in proximity to the calculus or a part of the collecting system from where the stone can be reached.
2. The majority of stone-bearing kidneys have a delicate, unobstructed collecting system.
3. The tract has to be dilated to admit large-calibre instruments.
4. Percutaneous nephrostomies are only the first step of a technically complex procedure requiring an array of special instruments, skills and technical facilities. The details of the approach chosen therefore not only depend on the individual anatomical situation, but also on the logistic possibilities of the hospital and the experience of the medical staff involved.

PATIENT PREPARATION AND POSITIONING

Renovascular malformations, in particular arterial aneurysms, are the only definite contraindications to percutaneous stone manipulation. They are extremely rare and reliably identified by routine sonographic screening of the kidney prior to puncturing the kidney. Clotting disorders likewise preclude percutaneous procedures. A clotting screen, which includes at least a platelet count and determination of the bleeding, prothrombin- and partial thromboplastin time, is therefore routinely obtained. Most abnormalities can be corrected by proper treatment, at least temporarily for the perioperative period. We successfully removed stones percutaneously from two patients with haemophilia A, after their factor VIII serum level was normalized by administration of factor VIII concentrates. Azotaemic patients frequently have a prolonged bleeding time with otherwise normal clotting tests, and preoperative administration of standard Red Cross cyroprecipitate has been recommended to correct this (Janson et al 1980). Hypertension in excess of 200/120 mmHg increases the risk of haemorrhage and should be controlled prior to percutaneous puncture.

Urinalysis and a urine culture are routinely performed preoperatively. In the presence of calculous disease, urinary infection frequently cannot be abolished by antibiotic treatment. Provided appropriate agents are administered for at least 48 hours prior to nephrolithotripsy, the postoperative course with infected stones does not differ significantly from that of patients without urinary infection. With clinical symptoms of acute infection in an obstructed system, in particular with signs of septicaemia, prior emergency drainage is mandatory. We routinely carry out percutaneous nephrostomy for drainage under local anaesthesia in these patients, and postpone percutaneous stone manipulation until the symptoms of septicaemia have disappeared under antimicrobial treatment and the urine has sterilized.

Thorough explanation of the procedure, of potential complications and, in particular, of the possible need for a staged intervention are, of course, essential for informed consent.

Whereas in obstructed kidneys an emergency nephrostomy can frequently be established virtually without anaesthesia, good analgesia is essential for successful lithotripsy. If the procedure is staged, the nephrostomy tract is usually established under infiltration anaesthesia with bupivacaine and sedation with small doses of diazepam and/or pethidine intravenously (Marberger et al 1982, Clayman 1983). The patient can then still co-operate sufficiently to suspend breathing on request during puncture. Local anaesthesia also permits intrarenal manipulation via a mature dilated nephrostomy tract, in particular when supplemented with butapharnol intravenously until the patient becomes drowsy or his speech becomes blurred (Clayman & Castaneda-Zuniga 1984). Clayman even performs complete one-stage nephrolithotripsy with this assisted local anaesthesia. The movement of large-calibre instruments within the kidney and intermittent distension of the renal capsule is, however, quite painful, and uneasiness of the patient impedes intrarenal manipulation. Regional intercostal (Ekelund et al 1980) or epidural anaesthesia (Alken et al 1983) provide good analgesia, but we prefer general anaesthesia with endotracheal intubation for more aggressive procedures.

Even if only a nephrostomy is established under local anaesthesia, the patient should be kept fasting for some hours preoperatively to reduce vomiting. For a brisk diuresis, fluid is provided intravenously during this phase. The administration of 12.5 g mannitol intravenously, just before commencing with intrarenal manipulation, reduces the risk of intratubular reflux and probably pyelonephritis (Alken 1982). If the nephrostomy is established under fluoroscopic control, the bolus injection of intravenous contrast dye (600 mg iodine/kg) given to opacify the kidney at the time of initiating anaesthesia probably fulfils the same purpose. It has the distinct disadvantage of camouflaging residual stones during lithotripsy, so that we prefer to administer it via the ureteral catheter prior to the puncture, as the dye is then rapidly washed out.

For percutaneous stone manipulation the patient may be placed in a prone oblique position (Kellet 1983), the prone position (Marberger 1983a, Smith & Lee 1983) or the supine oblique position (Goodwin et al 1955, Günther et al 1979). The latter position, with elevation of the flank to be punctured, is most comfortable for the patient, but the needle must be advanced horizontally. This makes guidance under conventional vertical beam fluoroscopy difficult as anterior or posterior deviation of the needle is difficult to assess. In addition, sterile endoscopic manipulation is virtually impossible due to the lack of manoeuvring space lateral and posterior to the patient; the position is unsuited for nephrolithotripsy.

In the prone oblique position with the patient rotated to 30°–45° obliquity, the skin puncture site lies directly over the point of entry into the pelvicalyceal system. When vertical beam fluoroscopy is used for guidance the two points are superimposed, so that the puncture can be performed in a vertical direction onto the calyx, parallel to the beam of fluoroscopy (Fig. 5.8). Provided the needle is advanced to the correct depth in this direction, puncture is simple. The technique becomes difficult when the needle has to be angled under the costal arch. By comparing the relative movements of the needle tip and the target calyx during respiration, the depth of the needle can frequently be judged by parallax, even under single plane fluoroscopy (Kellett 1983). The use of additional ultrasonic guidance, or biplane fluoroscopy, or the C-arm in two different positions obviates the problem. The main disadvantage of the prone oblique position lies in the high radiation exposure to the physician's hands, in particular when an overhead tube is used. This may be partially reduced by the use of the Amplatz nephrostomy handle (Rusnak et al 1981) and by inserting the needle in small steps, with repeated intermittent fluoroscopy after retracting the hands. Once intrarenal manipulation has to be monitored, as for the passage of a guidewire, this becomes impossible and so most advocates of the prone oblique position therefore then change the position to the pure prone posture (Clayman & Castaneda-Funiga 1984).

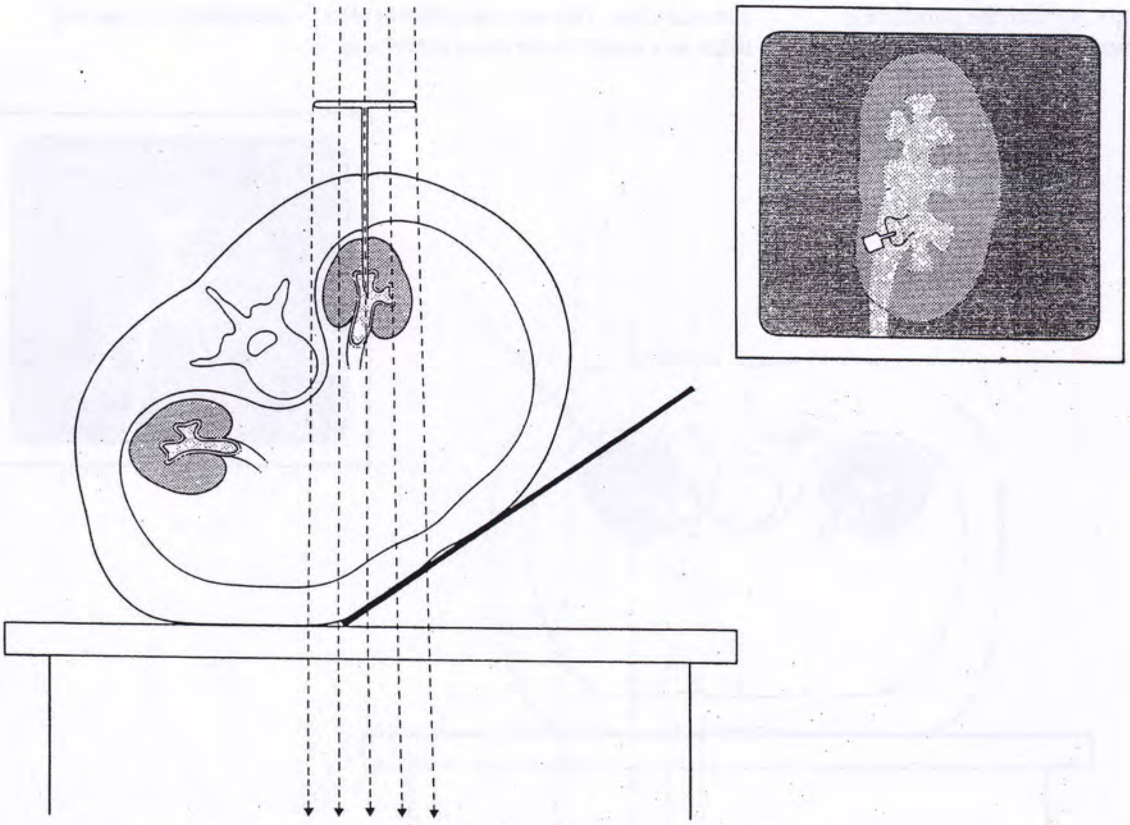


Fig. 5.8

Puncture of a posterior, inferior calyx in the prone oblique position, with vertical beam fluoroscopy.

Nephrolithotripsy is frequently carried out as a staged procedure. With an immature tract this requires identical positioning of the patient at each session to regain the straight tract through the various layers of the abdominal wall. Experience has shown that this is difficult in the prone oblique position and that barely noticeable variations in obliquity may result in considerable interweaving of the muscular layers along the tract. The prone position is simple to reproduce and under local anaesthesia the patient can maintain it with less discomfort than in the prone oblique position. The vertical puncture techniques described above cannot, of course, be employed in this position when using vertical beam fluoroscopy, so that the puncture is more difficult due to the angled image of the needle (Fig. 5.9). By combining fluoroscopy with ultrasonic guidance, or using biplane fluoroscopy, or a C-arm in two different positions this disadvantage can easily be overcome. In view of the enormous advantage, that the physician can keep his hands out of the primary beam at all times, in particular when carefully coning down the field, and the simplicity of reusing the tract in staged procedure, we use the prone position exclusively.

For routine nephrolithotripsy the patient is anaesthetized and intubated in the lithotomy position. A ureteral catheter is routinely advanced to the kidney to be treated, and connected to an extension line for easy injection of contrast dyes. The ureteral catheter also helps as a guide to the renal pelvis and ureter in orientation on the fluoroscopy screen and at endoscopy. Finally, as it remains in place during the entire procedure, it prevents stone fragments from slipping down to the ureter during the manipulation. Double-lumen balloon-tipped ureteral catheters are more effective, but are costly. We use them only in stones of exceptional size, where extensive intrarenal stone disintegration is to be anticipated. As the ureteral catheterization should not add to the morbidity of the procedure, the catheter is routinely placed under anaesthesia and always removed before the patient wakes up. With the continuous-flow nephroscope, the amount of irrigation fluid passed into the bladder is usually low, so that a urethral catheter is not routinely inserted.

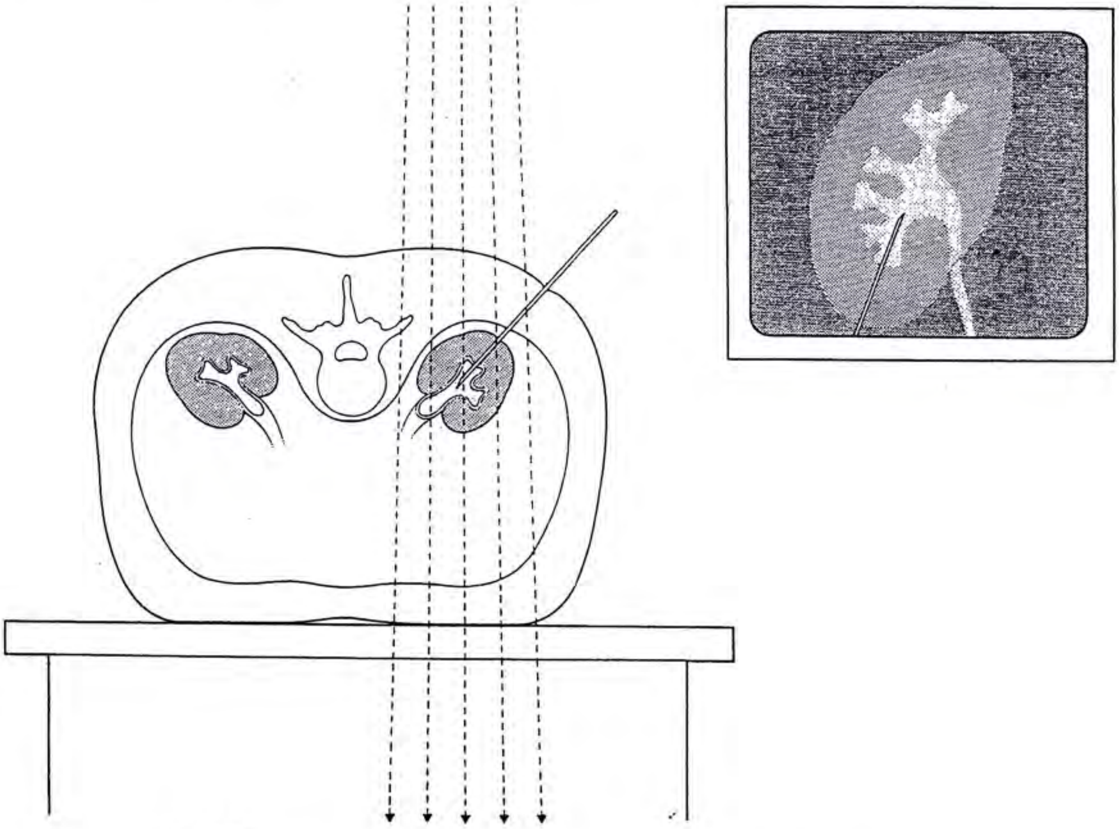


Fig. 5.9

Puncture of a posterior, inferior calyx in the prone position with vertical beam fluoroscopy.

The patient is then turned into the prone position. Correct endotracheal anaesthesia is mandatory, as the anaesthetist will not be able to readjust the tube once the patient is prone. Foam rubber rolls are arranged on both sides of the chest to allow for respiratory excursion, and arms and feet must be well padded. Only with extremely mobile kidneys is a foam rubber cushion placed in the hypochondrium under the kidney to stabilize it for puncture. After routine sonography of the kidney and the perirenal space, the flank is prepped as for open surgery and draped with a disposable waterproof transurethral prostatectomy drape. Its overflow funnel collects all irrigation fluid and drains into a bucket placed on the floor via plastic tubes (see Fig. 5.10). It is imperative to prevent leakage of saline into the radiological equipment, as this may cause electrical hazards. All instruments for the percutaneous procedures are arranged on a side table and a sterile scrub nurse assists with the procedure.

IMAGING EQUIPMENT AND ENDOUROLOGY SUITE

If the procedure is planned as a one-stage procedure, the patient should not have to be moved during the procedure from one room to another. The endourology suite should therefore be fully equipped with all facilities for general anaesthesia, and a table that permits positioning in the lithotomy position and the prone or the prone oblique position. To avoid the need for turning the patient in anaesthesia 180° around the body axis, when changing from the lithotomy position to the prone position, the table should be accessible from at least two long sides and one short lithotomy side. Good imaging facilities are decisive for success and this should also include the possibility of obtaining good-quality still-image films during the procedure for controlling the completeness of stone removal. Although the procedure should be performed under aseptic conditions like open surgery, the quality of the imaging equipment is significantly more important for the outcome of the procedure than the feasibility of performing open surgery on the same table. In the last 1000 patients subjected to percutaneous stone manipulation in our unit, not one patient underwent open surgery during the same anaesthesia. The endourology unit therefore need not be a surgical theatre fully equipped for open surgery; a sterile setting as used for other invasive percutaneous techniques, like percutaneous angioplasty, suffices.

With sonography readily available to many urologists, ultrasound-guided puncture has become popular in percutaneous nephrostomy of obstructed kidneys. With B-mode scanning and sterile biopsy transducers (Pedersen et al 1976) or transducers with attachable puncturing devices (Walz et al 1981) dilated collecting systems can be delineated sufficiently for puncture, but real-time sonography is more practical (Baron et al 1981) as it permits simultaneous visualization of the kidney, calculus and needle.

The most obvious advantage of ultrasonic guidance lies in the fact that opacification of the collecting system is not required. This is difficult to achieve in a poorly functioning kidney, especially if retrograde catheterization fails. The dye also camouflages calculous material. Even with the most sophisticated equipment, some details of importance for precise placement of the nephrostomy cannot be delineated sonographically in non-dilated collecting systems, such as the calyceal infundibula (Alken et al 1983). Fluoroscopic control therefore remains essential for nephrolithotripsy, in particular as it is also needed during the stone manipulation itself. Unless biplane fluoroscopy is available, sonography is most helpful as an adjunctive imaging technique to conventional vertical beam fluoroscopy. After preliminary screening of the kidney it can be used to decide on the optimal puncture sites on the skin and in the collecting system, the necessary angulation of the needle and the depth to which the needle must be advanced. With some experience it suffices to mark the point of skin entry and to memorize the angle and depth, and then insert the needle under fluoroscopic guidance (Stables & Johnson 1979, Hruby 1987).

The choice of the fluoroscopic equipment mainly depends on availability. Urological tables with overhead tubes are ideal from the aspect of adequate space for sterile manoeuvring during lithotripsy, but the radiation exposure of the surgeon is increased at least 100-fold as compared to radiological tables with under-table tubes (Bush et al 1984, Fig. 5.10). Together with logistic consideration and the co-operation of urologist and radiologist, this may be the reason for performing nephrolithotripsy as staged procedures rather than a one-stage nephrolithotripsy. With protective shielding, in particular of the eyes and thyroid, scrupulous collimating of the exposed field and the use of modern image-intensifying systems with 'freeze' monitors, the radiation hazard can be reduced to an acceptable level. When puncturing the kidney with the patient in the prone position, the physician's hands are always outside the primary beam, so that clumsy lead gloves are not necessary. Although we use over-table tubes, routine ring dosimetry has never indicated radiation exposure to the hands exceeding the legal limits. Fluoroscopy units with the X-ray tube beneath the table entail virtually no significant radiation hazard to the physician, as the patient's body absorbs almost 99% of the primary beam intensity and most of the secondary scatter radiation. Units of this type, which are mainly used for angiography, have the major disadvantage that the image-intensifier cannot be elevated more than 20–30 cm above the patient's body without a rapid loss in imaging quality. In our experience this causes significant problems with sterile manipulation over the patient. Percutaneous nephrolithotripsy can certainly be performed under these conditions, but we consider it more difficult than with overhead tubes.

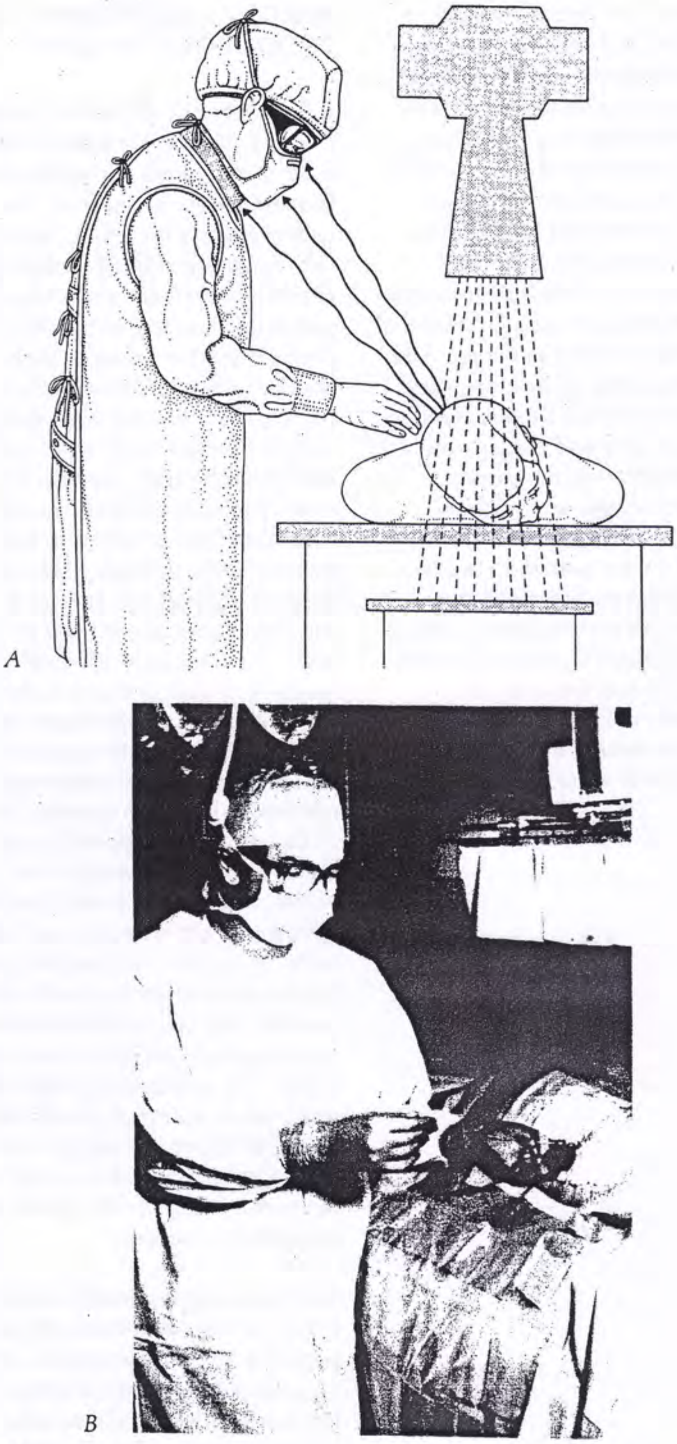


Fig. 5.10

(*A* and *B*) Scatter radiation with over-table fluoroscopy tubes, requiring protective shielding of the surgeon's eyes, thyroid and body. Note sterile, waterproof draping of the patient and ample space for sterile manipulation between fluoroscopy tube and patient. The surgeon's hands are outside the primary fluoroscopy beam.

If the standard diagnostic fluoroscopy unit is not available, a C-arm can be used alternatively on a radiolucent table in an operating theatre. With this equipment the beam of fluoroscopy may be adapted to the individual situation. By utilizing it in two different positions, three-dimensional orientation is simplified. The resolution and still-image film quality of C-arm units is usually poorer, and they also have significant scatter radiation, in particular when a tilted beam is utilized.

The ideal endourology suite today combines ESWL and endourological techniques in one room, preferably on one table. Several second generation lithotrites have been designed on the basis of this combined approach and today represent some of the most advanced equipment for this purpose. Their tables permit positioning of the patient, so that they can also be used for endourological procedures. If equipped with biplane fluoroscopy they are ideal for percutaneous puncture of the kidney, as the needle can be visualized in two planes at any time without having to change the position of the patient (Figs 5.11, 5.12).

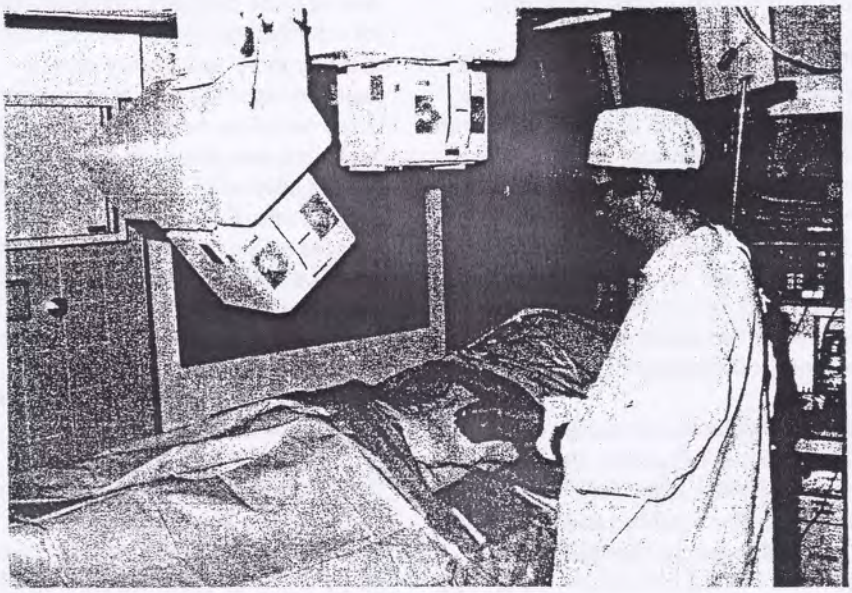


Fig. 5.11
Lithostar multipurpose lithotriptor (Siemens) with two separate overhead fluoroscopy units set at different angles for biplane fluoroscopy.

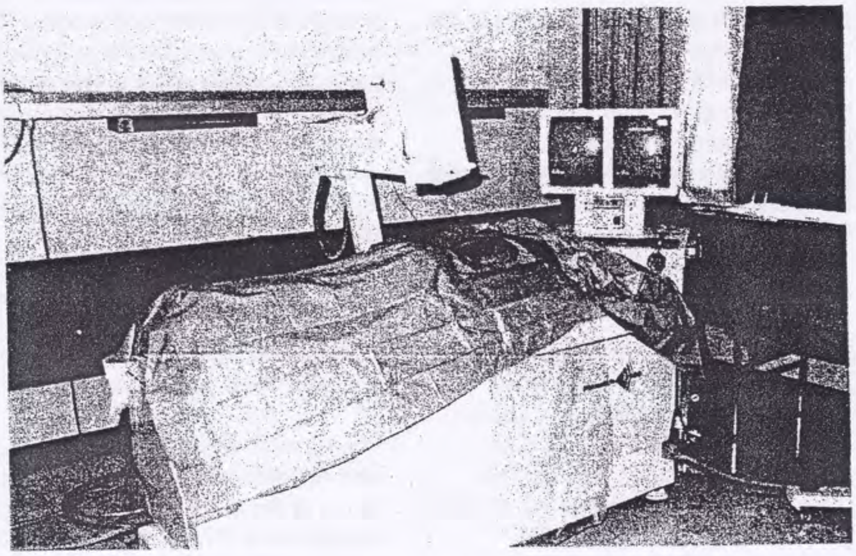


Fig. 5.12
Piezolith 2500 lithotriptor (Wolf) with in-line ultrasonography and in-line fluoroscopy; fluoroscopy is provided by an integrated C-arm which can be moved 30° for biplane fluoroscopy.

PUNCTURING THE KIDNEY

Percutaneous nephrostomies may be established directly with trocar-type cannulas (Goodwin et al 1955, Pedersen et al 1976, Newhouse & Pfister 1981), but this is too traumatic a method in a non-dilated collecting system and is therefore only rarely used for gaining surgical access for endourological procedures. In general one of the following variations of the Seldinger technique is employed:

1. The *catheter-over-needle method* (Fernström & Johansson 1976, Walz et al 1981, Kellett 1983, Schüller et al 1984): Teflon-sheathed needles as used for translumbar aortography are advanced to the collecting system. The needle is then withdrawn and a 0.35 guidewire is threaded down the soft sheath into the collecting system.
2. The *3-part coaxial needle set* (Günther et al 1979, Sadlowsky et al 1979) consisting of an outer blunt cannula, an inner 22-gauge bevelled needle and a stylet: the entire system is advanced through the abdominal wall to the fibrous capsule of the kidney. The collecting system is first punctured with the fine needle until the correct position is reached and the outer cannula is then advanced over it. After withdrawing the inner needle a guidewire can again be inserted.
3. The *skinny needle technique* (Cope 1982, Kellett 1983): the collecting system is punctured with a 21- or 22-gauge needle and a very fine 0.25 guidewire is threaded through the needle, which is then removed. A teflon-sheathed needle is fed over the guidewire, or the standard 0.35 guidewire is introduced with the help of a special stiffening cannula; a flexible dilator and the final nephrostomy sheath are then advanced over the larger guidewire.

Any of these methods can be utilized for establishing a percutaneous nephrostomy in virtually every clinical situation requiring this intervention. Every technique has its merits and drawbacks, but with adequate experience success rates of > 98% are achieved. In general, one of the above methods is adopted as the standard technique and modified according to the individual situation with growing experience. This trend and the commercial interest of the manufacturers, has multiplied the number of commercially available nephrostomy sets.

The limited availability of fluoroscopy facilities for urologists and the increasing experience with ureterorenoscopy and retrograde endourology has also sparked interest in retrograde nephrostomy techniques (Hunter et al 1983, Lawson et al 1983). With these methods a catheter is directed into a calyx suitable for percutaneous access in the retrograde direction via the ureter. The catheter serves as a sheath to guide a semi-rigid needle stylet to this point, from where it is then advanced through the parenchyma and abdominal wall in an outward direction to be retrieved outside the skin. The nephrostomy is established over the puncture wire. Special tip-deflecting catheters and torque wires permit precise placement of the wire in the correct calyx, and success rates of over 96% have been achieved (Hosking 1986).

We use exclusively an antegrade nephrostomy technique in a modification of the method first described by Günther et al (1979). All instruments are commercially available in a prepacked set (Fig. 5.13). With the patient under general anaesthesia and in a prone position, the kidney is first screened by sonography to determine the optimal puncture sites of the skin and the collecting system and the necessary angulation of the needle and the depth to which it has to be advanced. Diluted contrast dye is then injected via the ureteral catheter to delineate the collecting system. The point of entry of the tract into the pelvicalyceal system depends on the position of the calculus, the anatomy of the collecting system and the position of the kidney in relation to the 12th rib. In the majority of stone-bearing kidneys a posterior lower pole calyx provides good access to the lower pole calyces, the pelvis and, with some limitations, the upper-pole calyces (Fig. 5.14). In low kidneys with calculi in the middle calyces, these may be punctured directly; this access is also the approach of choice when manipulation at the ureteropelvic junction or in the proximal ureter is anticipated. Isolated stone-bearing calyces, obstructed calyces or calyceal diverticula are approached directly. If the stones are large enough and well visualized at fluoroscopy, puncture may even be performed without retrograde injection of contrast dye. With staghorn calculi or very large stones, the point of entry should be at the calyx, which permits the removal of the largest portion of the stone, in particular the largest side extension from the pelvis into a calyx. Some authors (Clayman & Castaneda-Funiga 1984, Dyer 1986) recommend puncturing the collecting system at the calyceal-infundibular border to avoid damage to the papilla. With this approach, the peri-infundibular veins are more likely to be injured (see Fig. 5.7) and with small calyces the calyx may be missed. As anatomical studies (Lutzeyer et al 1975, Boyce et al 1979) and extensive experience with radial nephrolithotomy failed to provide evidence for significant damage to the papilla by splitting it in the radial direction, and this plane is also the least vascularized, we routinely puncture the collecting system at the calyceal cusp.

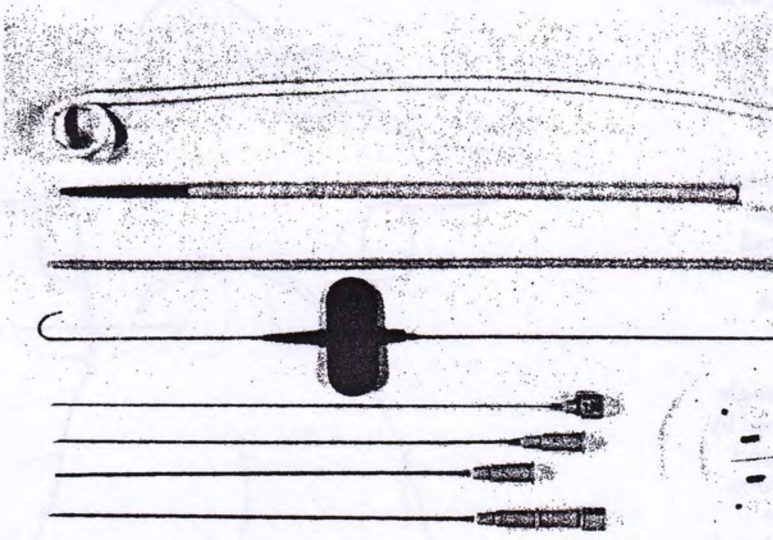


Fig. 5.13

Standard percutaneous access set consisting of three-part coaxial needle, semirigid 0.035 Lunderquist guidewire with 5 cm flexible J-tip, 8 F fascial dilator, 10 F fascial dilator backloaded with 12 F introducer sheath, 10 F pigtail nephrostomy tube, retaining disc for securing the nephrostomy at the skin level and connector to urine bag (Angiomed).

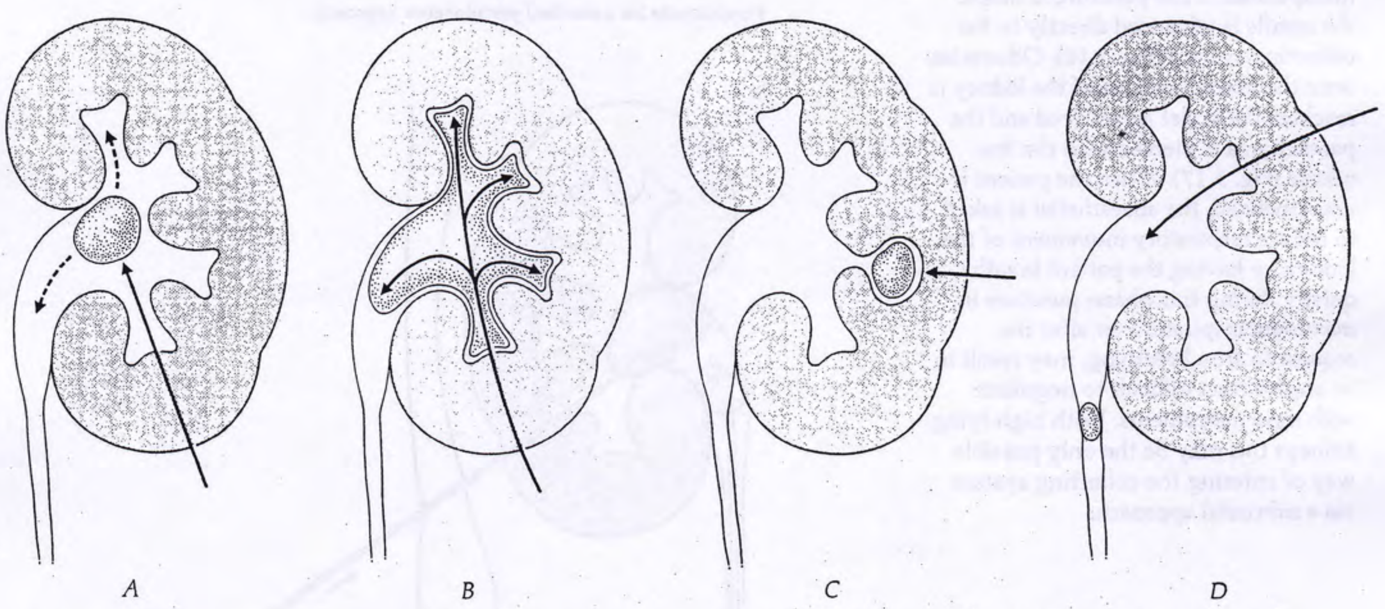


Fig. 5.14

Ideal access to (*A*) the standard pelviceal stone, (*B*) branched stone, (*C*) stone in calyceal diverticulum and (*D*) stones in the upper ureter.

To reduce the risk of tube-kinking in the supine position, the tract should enter the skin from the dorsolateral aspect of the flank at an angle of approximately 45° to the sagittal plane. In an adult patient this is usually along the posterior axillary line, just below where it crosses the 12th rib or an assumed extension thereof (Fig. 5.15). A small stab wound is made down to the superficial fascia, and the three-part needle with the stylet in place is advanced to the kidney under the vertical beam fluoroscopy, in the angle of puncture that was first established by sonography. The latissimus dorsi and serratus posterior inferior, which form this part of the abdominal wall, are relatively thin and easily traversed, and the 12th intercostal nerve and vessels are protected by the 12th rib. With some experience the renal capsule is felt as it is reached with the needle, and the kidney, respective stone and ureteral catheter can be seen to move on the fluoroscope screen as the kidney is manipulated. If the puncture is simple the needle is advanced directly to the collecting system (Fig. 5.16). Otherwise, once the fibrous capsule of the kidney is reached, the stylet is removed and the parenchyma is pierced with the fine needle (Fig. 5.17). When the patient is anaesthetized, the anaesthetist is asked to reduce respiratory movement of the kidney by having the patient breathe quietly during this phase; puncture in maximum inspiration, or after the request to stop breathing, may result in an angled tract difficult to negotiate with rigid instruments. With high-lying kidneys this may be the only possible way of entering the collecting system via a subcostal approach.

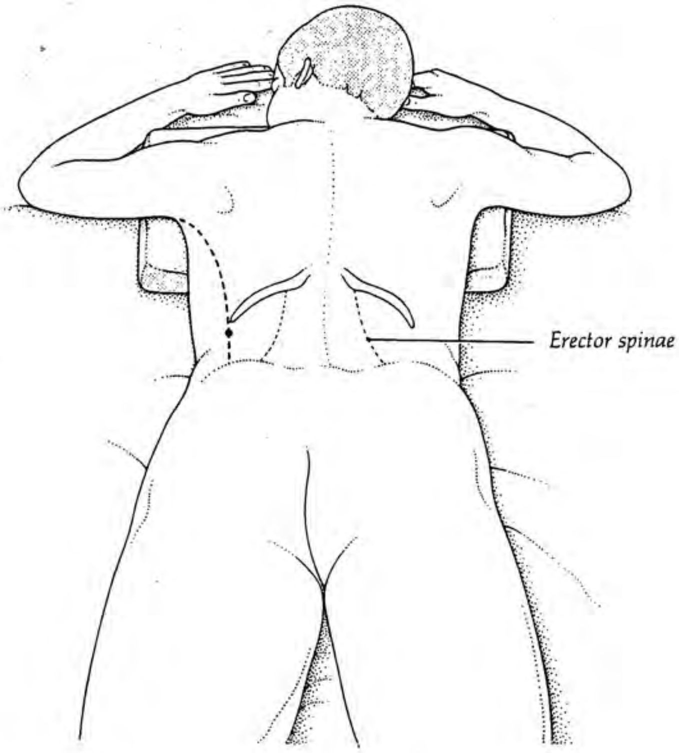


Fig. 5.15
Puncture site for a standard percutaneous approach.

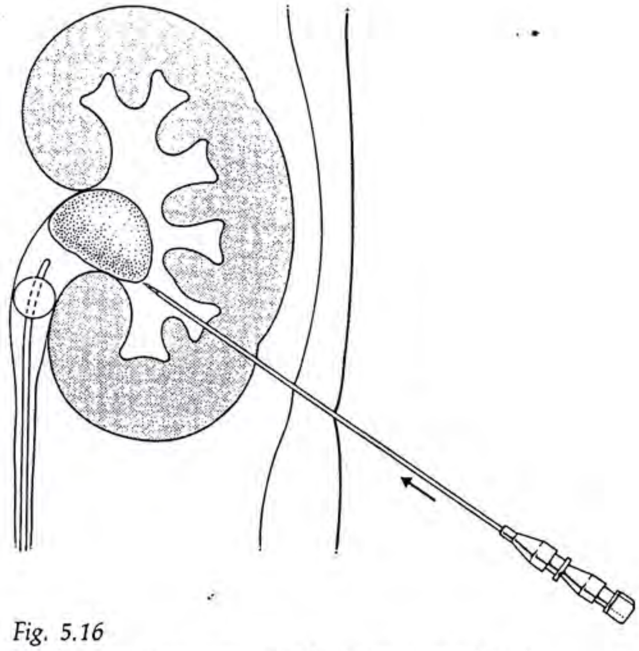


Fig. 5.16
Simple percutaneous puncture with 18-gauge coaxial needle.

In a kidney with a dilated collecting system the experienced endourologist will notice a slight give on entering the collecting system, but in a non-dilated system urine dripping from the needle is the usual sign of successful puncture of the collecting system. The inner needle is removed leaving the outer cannula in place. If contrast dye was injected via the ureteral catheter it usually drips freely from the cannula (Fig. 5.18), and identification is made even more easy by adding methylene blue. With significant obstruction and dilatation the collecting system should now be emptied via the dripping needle to prevent extravasation of dye during subsequent dilatation, as this may obscure fluoroscopic details.

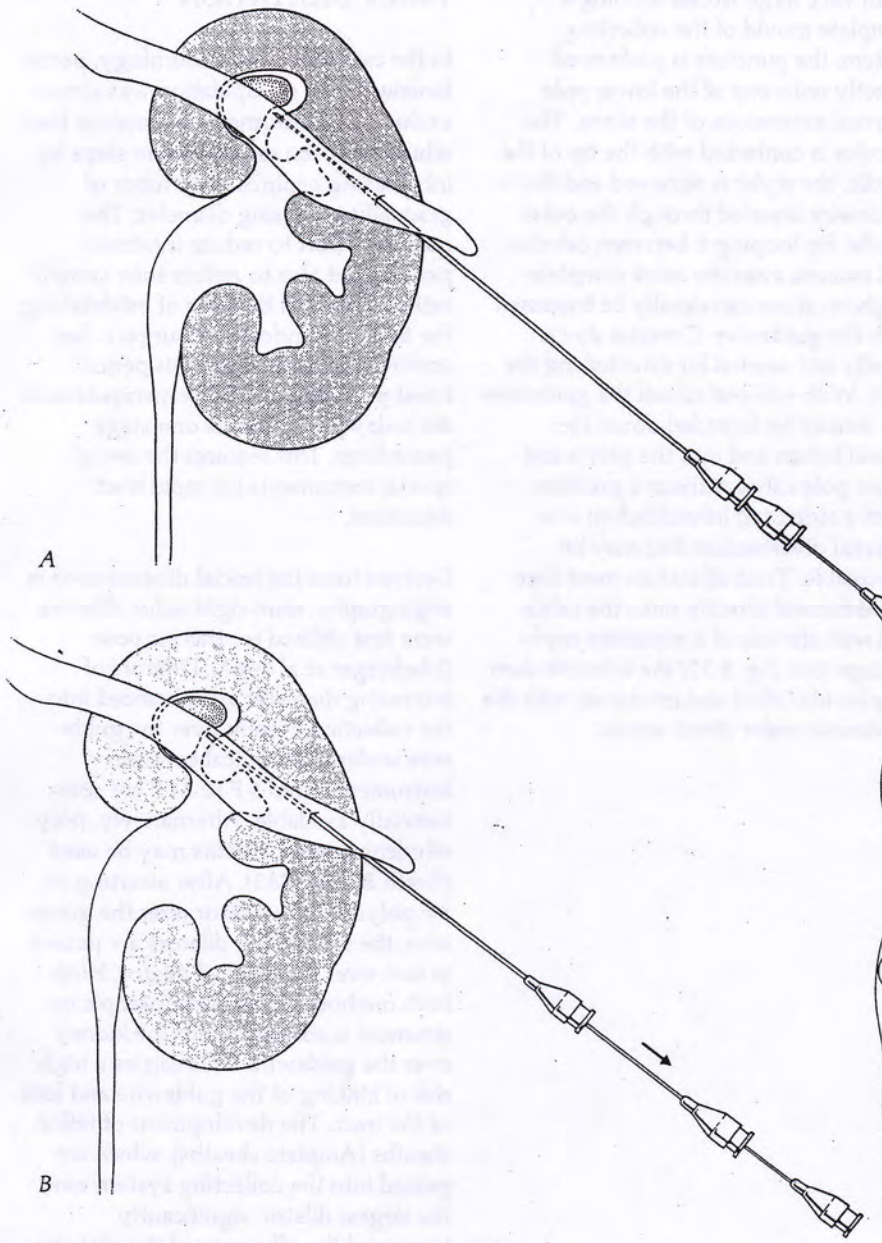


Fig. 5.17

Difficult puncture: 18-gauge coaxial needle is advanced only to the fibrous capsule of the kidney and the stylet is removed. A 22-gauge Chiba needle is inserted through the inner needle (*A*) and the collecting system is punctured with this skinny needle. If this is correctly achieved, the coaxial system is advanced over the skinny needle into the correct position. Both needles are now removed (*B*), leaving only the outer cannula in place.

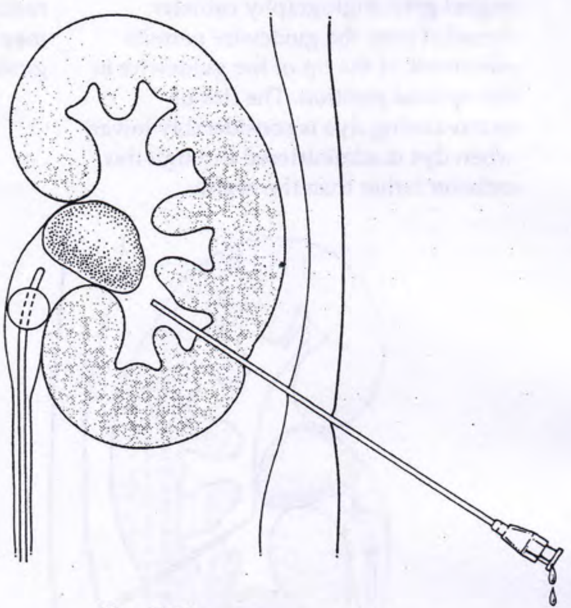


Fig. 5.18

Urine dripping from the cannula is the most reliable sign of puncture of the collecting system.

In case the needle does not drip properly, but a correct position seems likely, 18% contrast dye may be injected through the needle to delineate the collecting system. As extravasated dye obscures anatomical details, we usually prefer to introduce a 0.035 inch guidewire with a soft J-tip. It is fed down the cannula and into the collecting system under fluoroscopic control. In case of resistance or an obviously inappropriate position, it is withdrawn with the needle and the puncture is repeated. If in a correct position, it directs the successive dilators, instruments or tubes and prevents loss of the tract if any problems develop at this time. It is therefore essential to advance it into the collecting system as far as possible, preferably into an upper pole calyx (Fig. 5.19) or down the ureter. If this is not achieved by twisting the guidewire, an angled gray angiography catheter threaded over the guidewire permits placement of the tip of the guidewire in the optimal position. The risk of extravasating dye is considerably lower when dye is administered through this catheter rather than the needle.

With very large stones forming a complete mould of the collecting system, the puncture is performed directly onto one of the lower pole calyceal extensions of the stone. The calculus is contacted with the tip of the needle, the stylet is removed and the J-guidewire inserted through the outer needle. By looping it between calculus and mucosa even the most complete staghorn stone can usually be bypassed with the guidewire. Contrast dye is usually not needed for establishing the tract. With calyceal calculi the guidewire can usually be threaded down the infundibulum and into the pelvis and upper pole calyx without a problem. With a strictured infundibulum or a calyceal diverticulum this may be impossible. Tract dilatation must then be performed directly onto the calyx, and with the use of a miniature nephroscope (see Fig. 5.37) the infundibulum may be identified and intubated with the guidewire under direct vision.

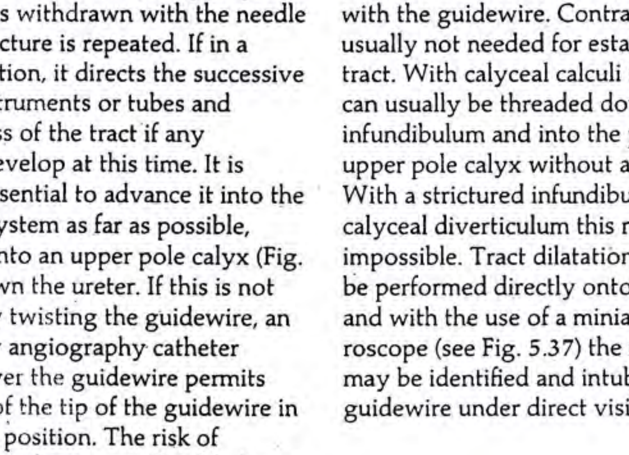


Fig. 5.19

A Lunderquist guidewire is threaded through the cannula and advanced as far as possible into the collecting system to secure the tract.

TRACT DILATATION

In the early days of endourology, percutaneous stone manipulation was almost exclusively performed via a mature tract which had been established in steps by introducing nephrostomy tubes of gradually increasing diameter. The constant effort to reduce treatment periods, but also to reduce tube complications between the time of establishing the tract and endoscopic surgery, has continuously shortened this period. Most percutaneous stone manipulations are today performed as one-stage procedures. This requires the use of special instruments for rapid tract dilatation.

Derived from the fascial dilators used in angiography, semi-rigid teflon dilators were first utilized for this purpose (Marberger et al 1982). Dilators of increasing diameter are advanced into the collecting system over the guidewire under radiological control. Instruments from 5 F to 34 F are commercially available. Alternatively, polyethylene coaxial dilators may be used (Smith & Lee 1983). After inserting an 8 F polyethylene dilator over the guidewire, the succeeding dilators are passed in turn over the original dilator. With both methods the final endoscopic instrument is advanced into the kidney over the guidewire. This carries a high risk of kinking of the guidewire and loss of the tract. The development of teflon sheaths (Amplate sheaths), which are passed into the collecting system over the largest dilator, significantly improved the efficiency of the systems (Rusnak et al 1982, Fig. 5.20). The dilators are removed through the sheath which stays in place during the manipulation and compresses the parenchyma along the tract, thus reducing intraoperative haemorrhage. In this manner any endoscopic instrument may be introduced through the sheath without traumatizing the kidney. The irrigation fluid drains freely around the instrument so that any increase in intrarenal pressure during endoscopic surgery is avoided. If the surgeon considers the continuous leakage of fluid and drenching of the field annoying, the system can be sealed with a snap-on cap and an overflow cannula (Rutner Sheath).

Properly used, semi-rigid instruments are safe and economical. With very dense tissues, particularly after multiple previous operations or in very mobile kidneys, they tend to buckle at the level of the fascia and fibrous capsule of the kidney. This can result in dislocation of the guidewire and a false passage. Metal dilators avoid this hazard. Alken (1981) developed a telescope-dilator system in which aerial dilators are advanced one over the other in increments of 3 F over a central metal rod. Nephrostomy tubes or the sheaths of nephroscopes may be inserted directly over the appropriate dilators which can then be retrieved through the lumen of the instrument with the help of the retriever knob on the kidney end of the central rod. In the original version presented by Alken (1981) this rod had no axial perforation, so that it could not be directed over a guidewire. This modification added substantially to the safety of the system (Marberger 1983a, Fig. 5.21). Passage of the fascial layer and scar tissue is further facilitated by cutting these structures with a rigid instrument with cruciate adjustable blades (Korth 1984, Fig. 5.22).

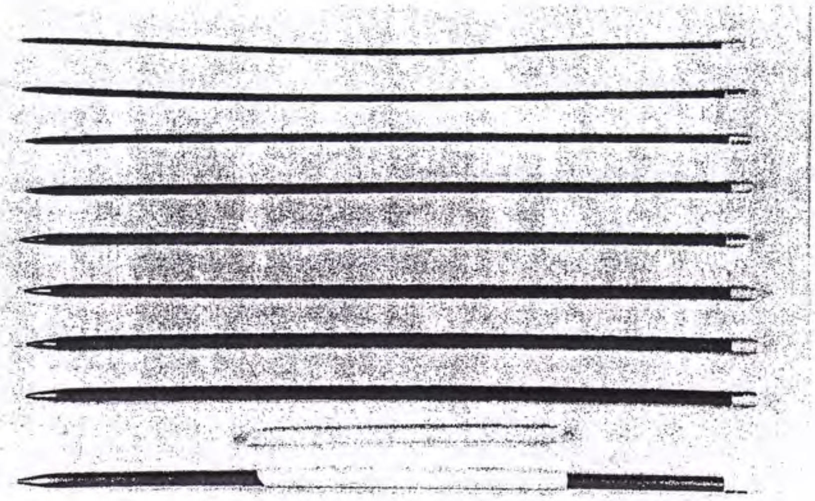


Fig. 5.20
Amplatz semirigid fascial dilators and Amplatz endoscope working sheath (Cook).

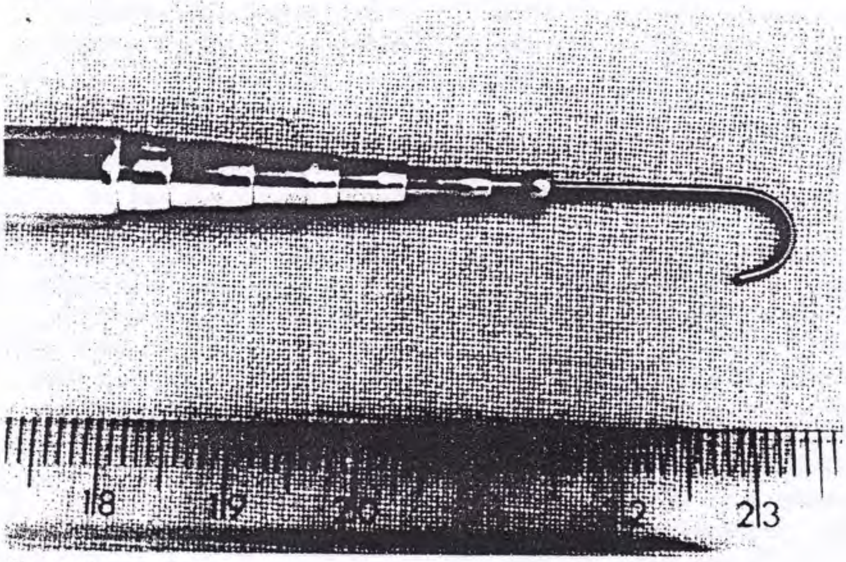


Fig. 5.21
Metal telescope-dilator system with axial perforation for Lunderquist guidewire; note the knob on the central rod for retrieving the dilators.

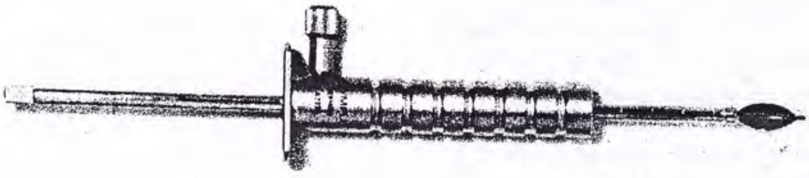


Fig. 5.22
Korth fascial incisor; the instrument is advanced over a guidewire to a preset depth depending on the thickness of the abdominal wall (Olympus).

Balloon catheters originally developed for transluminal angioplasty tolerate pressures in excess of 10 atmospheres and can be employed for rapid tract dilatation. With the balloon deflated the catheter is positioned over a guidewire, so that the balloon-covered part is located along the tract to be dilated. The balloon is rapidly filled with diluted contrast dye to inflate it along the entire tract. With obese patients, repeated inflation and deflation of the balloon and repositioning of the catheter may be required. After several seconds the balloon is collapsed again, the catheter is removed and the endoscope is advanced into the tract over the guidewire. Clayman et al (1983b) solved the problem of buckling of the working wire and false passage when introducing the instrument by using a 10 mm Olbert angioplasty balloon catheter, which is backloaded with a teflon working sheath or nephroscope sheath. The balloon only needs to be inflated for several seconds; after deflation the backloaded instrument is slipped into the collecting system directly over the balloon.

No system is without drawbacks and complications; experienced endourologists use a variety of dilatation instruments. Semi-rigid dilators are safest for dilating the tract from the calibre of the puncture needle to approximately 16 F. Larger flexible dilators buckle at fascial layers and it may be extremely difficult to advance them through scar tissue. Metal dilators are highly efficient and safe once the central rod is properly positioned in the collecting system and dilatation is performed under fluoroscopic control, but it may be difficult to insert the rod over the guidewire if the original tract was not straight. Balloon catheters are costly and are usually not reusable. With significant perirenal scarring they may not inflate completely when insufficient inflation pressures are used, and they may require repositioning during the dilatation phase. We therefore prefer a combined approach: dilatation of the tract to around 12 F with fascial dilators and subsequently to 24 F or 27 F as needed with the metal telescope dilators.

In detail this is performed as follows:

1. A red 7 F angiography catheter is threaded over the soft 0.035 inch J-guidewire and advanced into an upper pole calyx.

2. The angiography catheter is used to exchange the J-guidewire against a 0.035 inch Lunderquist guidewire (Fig. 5.23). It is made of rigid polished steel, but has a 5 cm soft floppy end with a J-tip. The floppy end is advanced into the collecting system. Once positioned properly, this guidewire will guide all dilators into the collecting system unfailingly, unless it is kinked by excessive tangential force. With a wide collecting system and a simple puncture the Lunderquist guidewire may be inserted primarily, so that the need for exchanging the guidewire is avoided.

3. The 8 F fascial dilator and the 10 F fascial dilator with the backloaded 12 F introducer sheath are advanced into the collecting system over the Lunderquist guidewire (Fig. 5.24). The introducer sheath is 4 cm shorter than the fascial dilator. As soon as the former is well within the collecting system, the sheath is unlocked from the dilator with a counter-clockwise twisting movement and also advanced to the collecting system; it slides smoothly over the 10 F dilator, the position of which is not changed. With correct placement of the sheath, the dilator is removed and a floppy 0.035 safety guidewire with a J-tip is inserted alongside the Lunderquist guidewire (Fig. 5.25). The soft guidewire serves as safety guidewire for retrieving the nephrostomy tract in case it is lost during the manipulation and it remains in place during the entire percutaneous procedure. If the intervention is terminated at this point, a 10 F pigtail nephrostomy tube can be inserted instead to establish reliable drainage. Otherwise the sheath is removed, taking care not to dislocate the two guidewires.

4. The axial rigid rod of the telescope dilator (see Fig. 5.21) is now inserted into the collecting system under fluoroscopic control over the Lunderquist guidewire. As the tract has already been dilated to 12 F, this is usually achieved without problems, if the correct angulation of the tract is maintained and excessive force against the guidewire is avoided. Otherwise the Lunderquist guidewire may kink and the sharp bend may not only prevent correct introduction of the telescope dilators, but may backlash the guidewire out of the kidney. Care should also be taken not to advance the stiff part of the Lunderquist too far into the collecting system, as it may kink at the junction of the floppy and rigid portions and may be pushed through the pelvis at this point. The ureteral catheter marks the pelvis fluoroscopically, and this facilitates correct placement of the axial rod. In general it is advanced to the pelvis, i.e. the ureteral catheter. With large stones it is only brought into contact with the stone. If dilators up to 24 F are forced by a very large stone within a tight collecting system this may be ruptured.

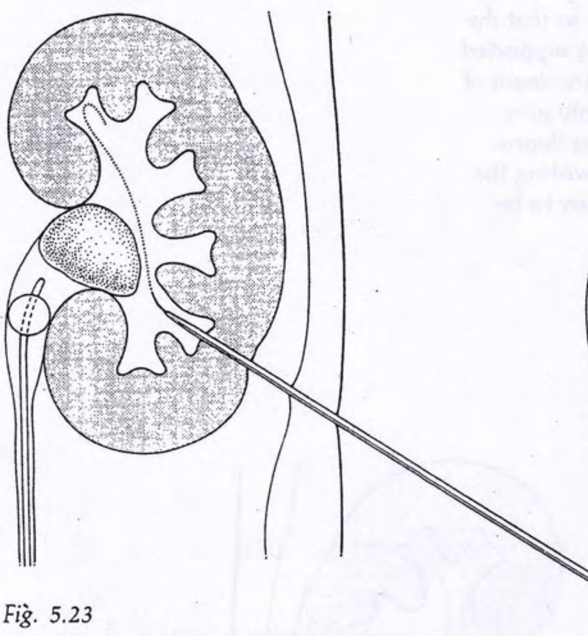


Fig. 5.23

Tract dilatation with fascial dilator over Lunderquist guidewire.

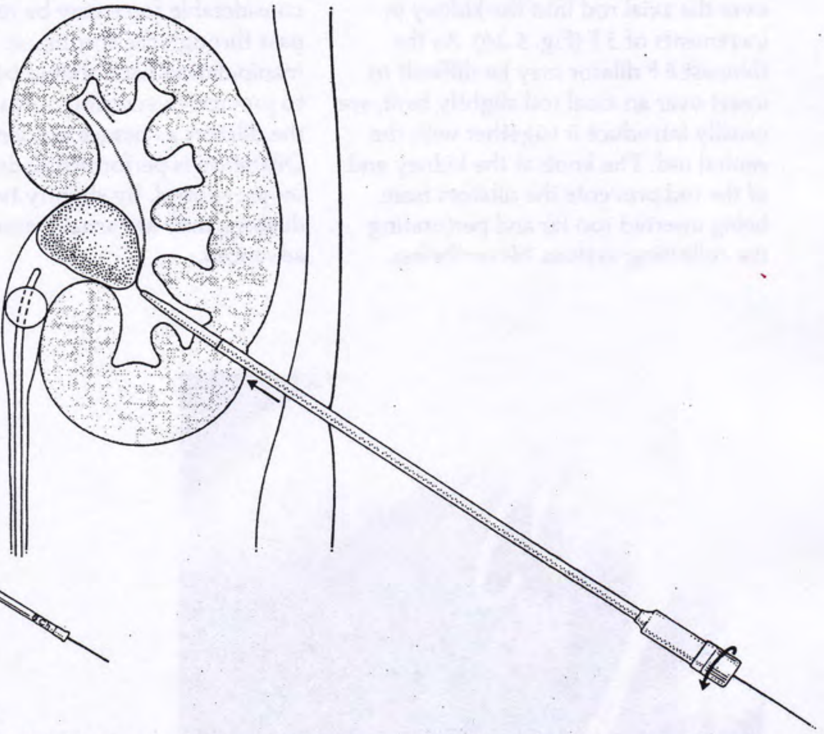


Fig. 5.24

After the 10 F dilator is advanced to the collecting system, the backloaded sheath is released from the dilator by a counter-clock twist and also advanced to the collecting system over the dilator.

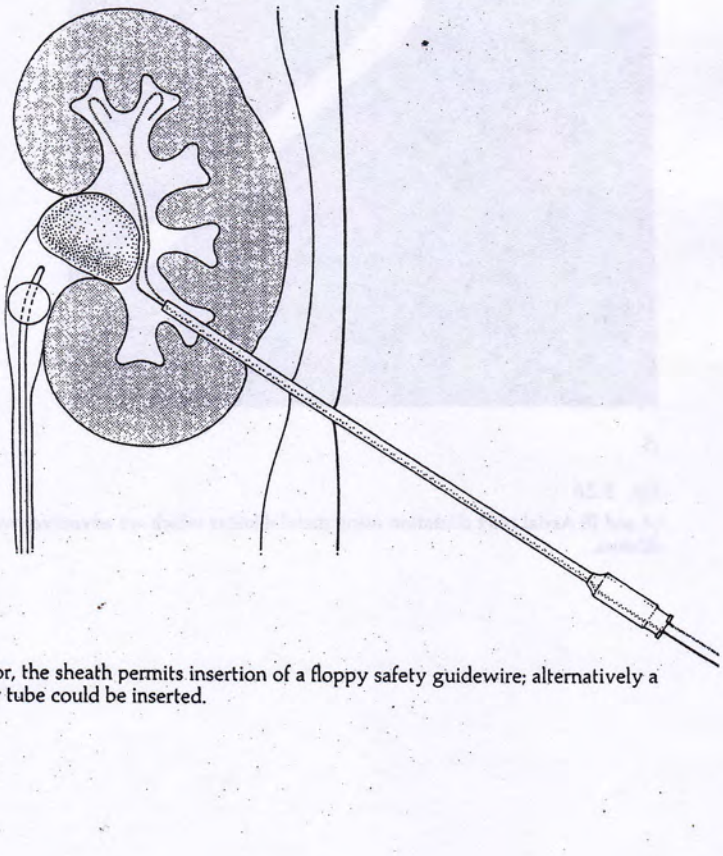


Fig. 5.25

After removing the dilator, the sheath permits insertion of a floppy safety guidewire; alternatively a 10 F pigtail nephrostomy tube could be inserted.

5. Aerial dilators are now advanced over the axial rod into the kidney in increments of 3 F (Fig. 5.26). As the thinnest 8 F dilator may be difficult to insert over an axial rod slightly bent, we usually introduce it together with the central rod. The knob at the kidney end of the rod prevents the dilators from being inserted too far and perforating the collecting system. Nevertheless, with severe perirenal scarring, considerable force may be required to pass through the scar tissue, so that the manipulating hand should be supported to prevent overzealous advancement of the dilators as tissues suddenly give. Dilatation is performed under fluoroscopic control. By slightly twisting the dilators, they are usually easier to be advanced.

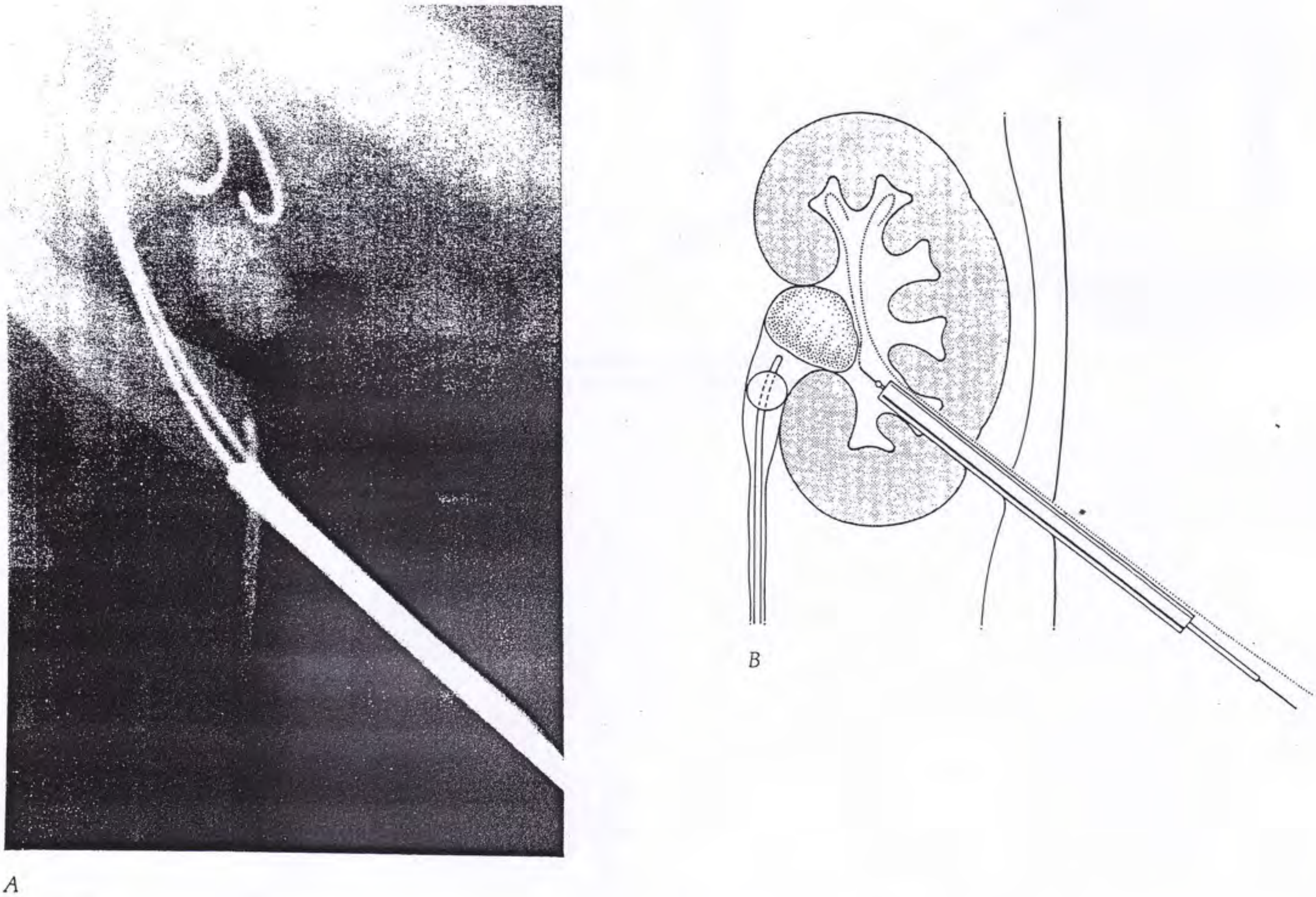


Fig. 5.26

(*A* and *B*) Aerial tract dilatation using metal dilators which are advanced over a Lunderquist guidewire; note safety guidewire in the same tract, outside the dilators.

6. As the final step, the sheath of the 24 F nephroscope is inserted over the 21 F dilator; if the 27 F nephroscope is used a 24 F dilator has to be inserted in addition. The dilators are removed through the sheath with the help of the retrieving knob at the end of the axial rod (Fig. 5.27).

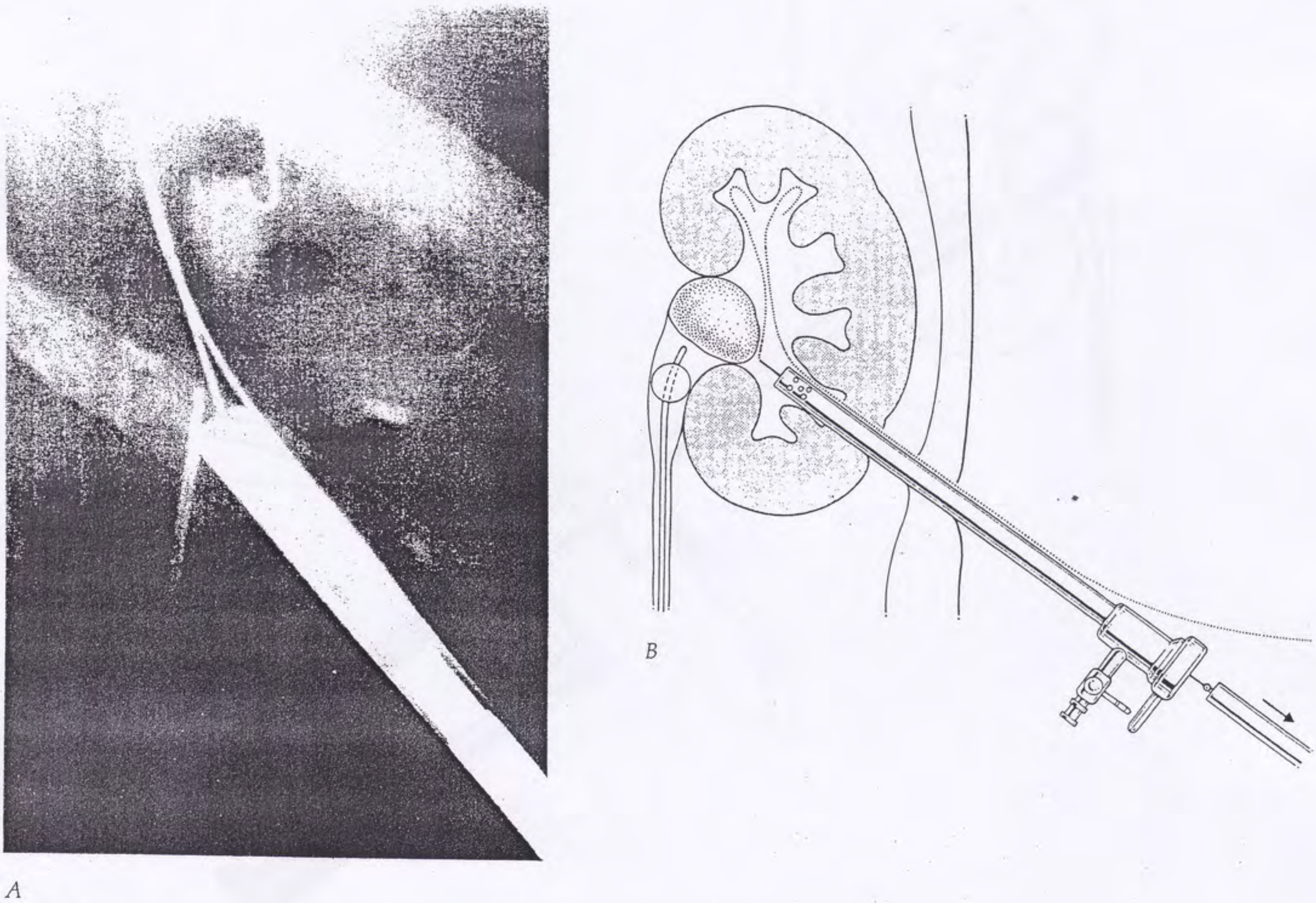


Fig. 5.27
(*A* and *B*) At the final step of dilatation the nephroscope sheath is advanced over the last dilator; the dilators are retrieved through the sheath.

7. The nephroscope is inserted through the sheath. In this phase we like to leave the Lunderquist guidewire in place and threaded through the nephroscope working channel (Fig. 5.28). The collecting system may still be filled with clots and orientation along the guidewire is helpful, especially as it is also seen on the fluoroscope screen. It is finally removed after the collecting system is clearly identified with the endoscope. The safety guidewire remains in place outside the sheath of the nephroscope. We do not routinely dilate the tract to more than 27 F.

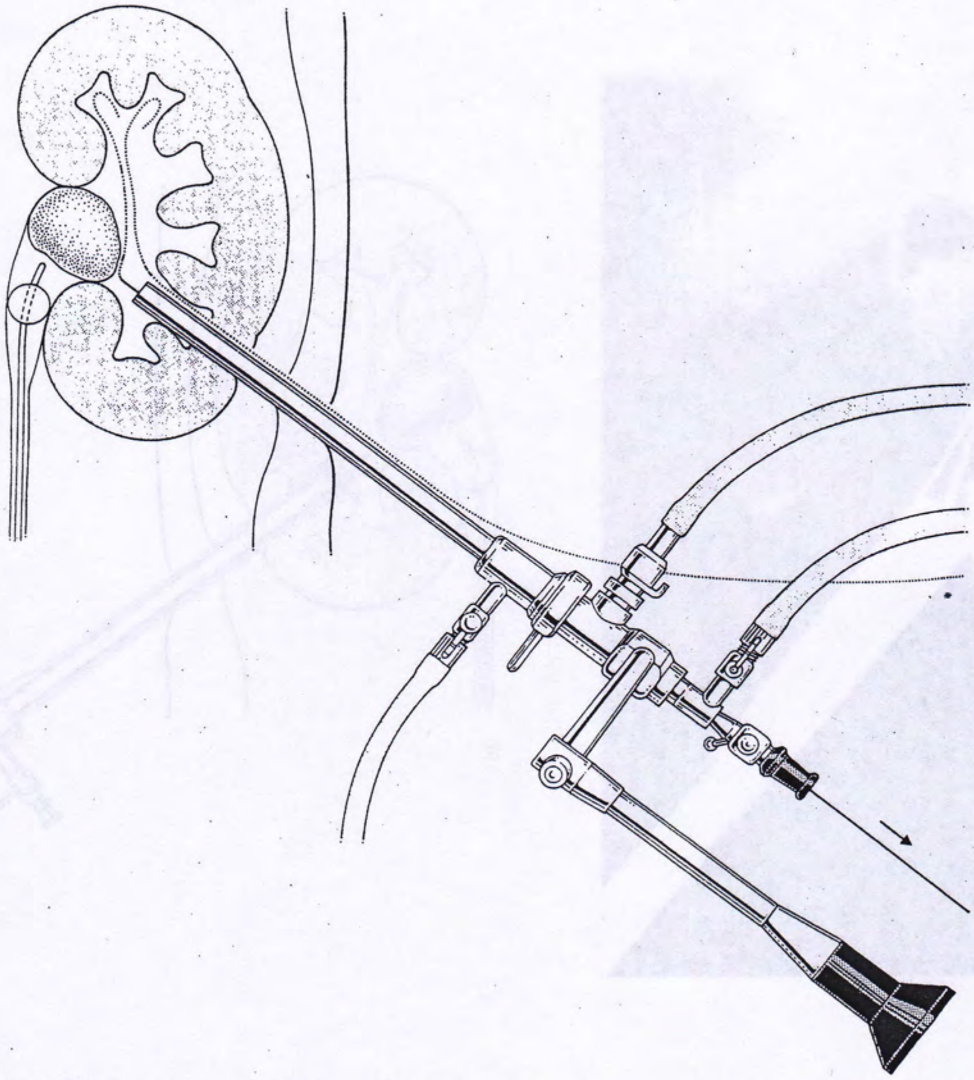


Fig. 5.28

The nephroscope is inserted through the sheath, over the Lunderquist guidewire to facilitate initial orientation.

NEPHROSCOPY

With the development of percutaneous nephrostomy techniques, tubes could be placed within the immediate vicinity of renal calculi. It was therefore only a natural next step to attempt their removal via the percutaneous tract. The pioneers of these methods relied on fluoroscopy for intrarenal guidance during stone manipulation (Fernström & Anderson 1977). In spite of the use of biplane fluoroscopy, steerable instruments or Mazzariello-Caprini forceps modified to follow a guidewire interposing soft tissue frequently resulted in failures. Rupel & Brown (1941) had already pointed out the potential solution: percutaneous nephroscopy. Endoscopes originally designed for the lower urinary tract facilitated percutaneous stone manipulation and, together with the improvement of percutaneous nephrostomy techniques, established percutaneous stone manipulation as a standardized treatment modality. In general, 30° 20–24 F panendoscopes or 20 F urethrotomes were used (Clayman et al 1983a, Miller & Wickham 1983, Smith & Lee 1983), which permitted antegrade vision without protruding instrument beaks. Irrigation was provided by gravity perfusion with saline, either intermittently through the in- and outflow channels of the instrument, or with an outflow down the ureter or along the instrument with the help of a nephrostomy sheath. The excellent optical quality of rigid rod-lens systems for the first time permitted true endoscopic inspection of the kidney and provided the basis for the first large series of patients treated percutaneously. The main disadvantage of the instruments was their lack of an operating port for direct approach to a calculus with a straight rigid instrument. Stones had to be removed with baskets or flexible forceps, which were difficult to manipulate inside the kidney, or too small for larger stones.

Rigid nephroscopes

The breakthrough came with the development of purpose-built nephroscopes. In 1981 we designed a 24.5 F universal nephroscope for percutaneous surgery (Marberger et al 1981, 1982). It incorporates a sheath and shaft system with a 15° endoscope and a straight 11 F working channel. The eyepiece of the endoscope was right-angled from the working port to permit sterile manipulation. An integrated continuous flow irrigation system provided a continuous exchange of irrigation fluid at high-flow rates; as the diameter of the outflow channel exceeded that of the inflow channel, an increase of pressure within the renal collecting system due to overfilling with irrigation fluid was avoided (Fig. 5.29a). The inflow channel, working port and endoscopes were integrated to one unit, so that the instrument could also be used without its sheath, for example within a nephrostomy sheath (Fig. 5.29b). Modifications of the irrigation system improved the flow rate to 650 ml/min with a free working port and to 420 ml/min with a 10 F instrument inserted at gravity perfusion at 60 cm (Marberger 1983a).

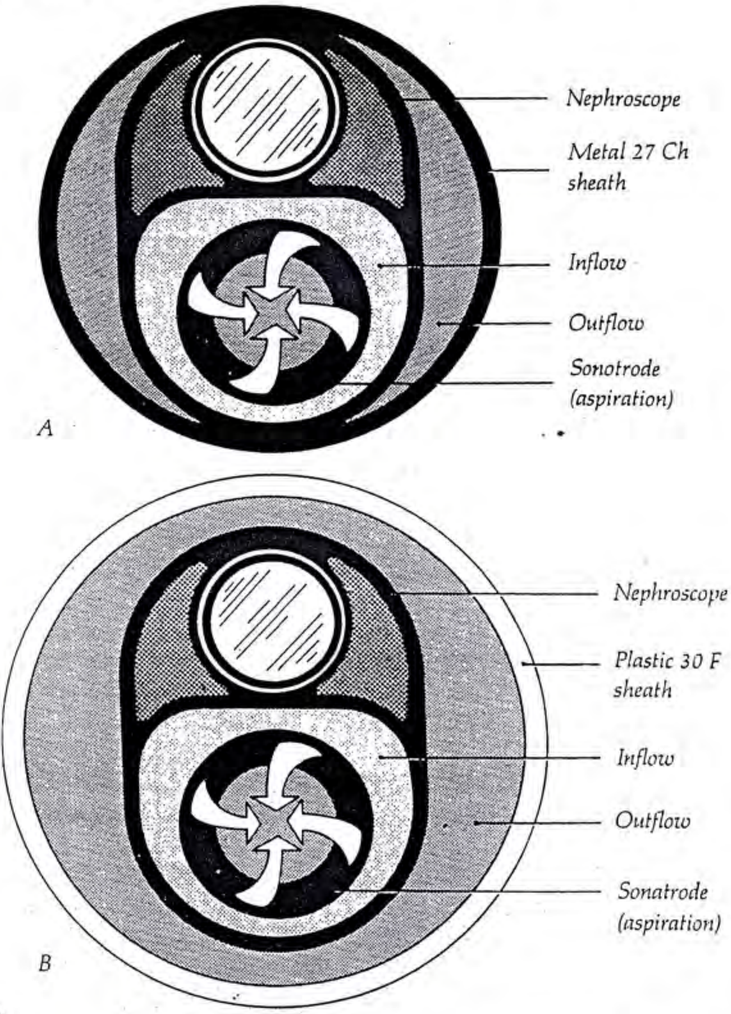


Fig. 5.29

Irrigation during nephroscopy using closed system (*A*) with nephroscope sheath and open system (*B*) with nephrostomy sheath.

The design principles of this nephroscope are, in general, employed in most commercially available nephroscopes today (Fig. 5.30) (Marberger 1983a, Miller & Wickham 1983, Korth 1983, Clayman & Castaneda-Zuniga 1984).

In obese patients and high kidneys the right-angle eyepiece of the instrument may interfere with the patient's buttocks, and it has also been claimed to have a 'back-heavy' lateral torque effect. Instruments with an acute-angle eyepiece were designed to avoid this disadvantage (Miller & Wickham 1983). They are easier to manipulate in difficult situations, yet many urologists find it unusual not to work in the direction of vision. The problem has also been eliminated by the development of nephroscope sheaths, which can be rotated 360° against the nephroscope.

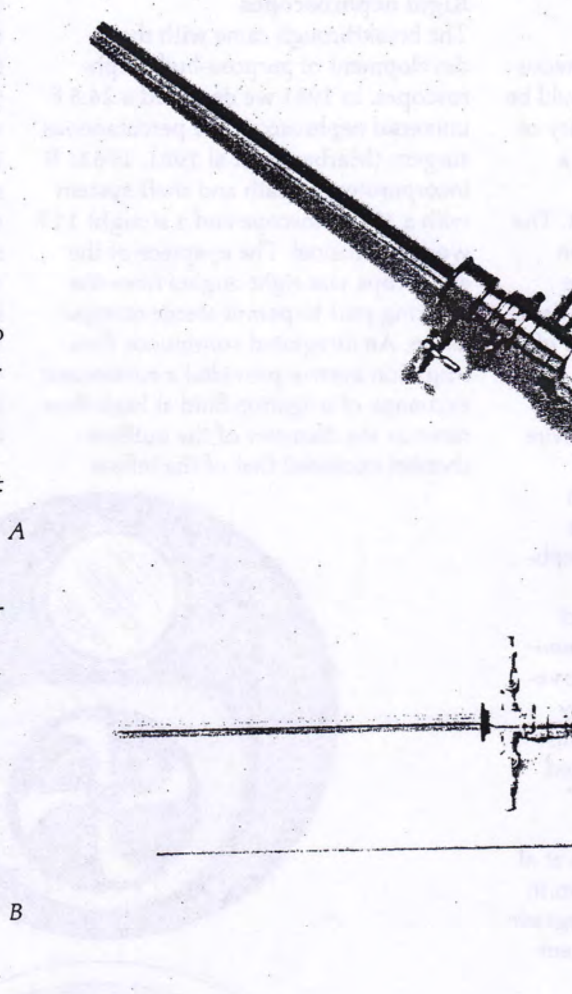


Fig. 5.30

Standard operating nephroscopes with continuous flow irrigation: (*A*) Olympus, (*B*) Storz, with sheath and endoscope separated, (*C*) Wolf, with ultrasonic probe inserted and separate 27 F sheath and alligator forceps.

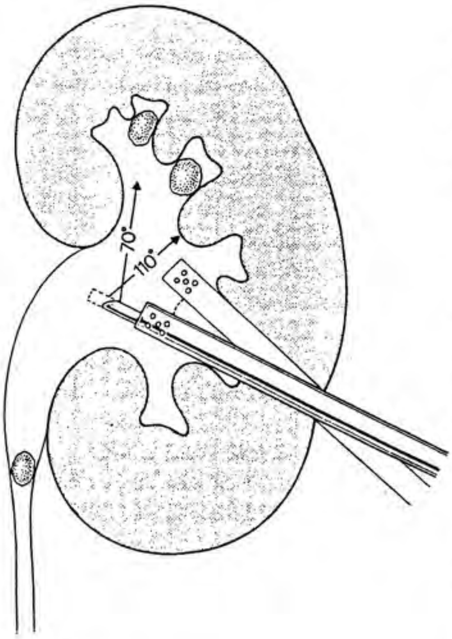


Fig. 5.31
Improved field of vision with insert telescopes with difficult angles of vision.

With straightforward 0°-vision, instruments introduced into the working port are only marginally visible and therefore difficult to control, so that a downward view of 10°–25° appears preferable. Wide angle 'fish-eye' lenses (> 100°) theoretically improve intrarenal orientation, but the systems presently available suffer from significant optical distortion in the margins of the optical field; although more complicated, the use of an additional insert telescope with a 70° or 110° angle through the working port provides a wider field of vision at better quality (Marberger 1983) (Fig. 5.31).

The same principles that apply for endoscopy of the lower urinary tract also fully apply for nephroscopy. Visual control of all manipulations is mandatory. This requires good irrigation and optical identification of the tissues in the vicinity of the endoscope. We use saline exclusively as an irrigant, as even with extensive extravasation it is rapidly eliminated without electrolyte imbalance. If non-electrolyte solutions as utilized for transurethral surgery are used, they may cause potentially lethal water intoxication similar to the 'TUR-syndrome', when extravasated outside the collecting system. It would certainly be preferable to warm the solution to 35°C, but for simplicity we routinely use 3-litre saline bags stored at room temperature and have not seen significant changes of body temperature even with prolonged procedures. The bags are suspended about 40–60 cm above the nephrostomy; a Y-perfusion system as used for transurethral surgery permits change of irrigant bags without interrupting irrigation.

Initially, in particular in one-stage procedures, clots may obscure the field. Occasionally they can already be cleared by simply manipulating the Lunderquist guidewire still in place within the working port of the nephroscope. If this fails, they are best removed with an aspirator advanced down the working port, or plucked from the collecting system with a special flat-alligator forceps. Once the collecting system has been cleared of clots, intrarenal orientation is mainly directed endoscopically. With some experience, mucosa, papillae, fatty tissue and even rents in the collecting system are readily visible. With continuous flow irrigation the collecting system remains rather collapsed and it may be difficult to identify side calyces. In this situation the tubing from the outflow port is best kinked temporarily to dilate the collecting system for better orientation. This should only be performed for seconds, and only if the stone cannot be flushed out of position.

For optimal vision the irrigation port connected to the working channel of the nephroscope is used as an inflow port and the space between the working element and the nephroscope sheath or the Amplatz sheath is used as an outflow port (see Fig. 5.29). In this manner the blood effluent is flushed away from the telescope, but stone debris likewise tends to be flushed out of the field. In spite of somewhat poorer vision, we therefore routinely reverse the direction of flow, i.e. use the working port as an outflow channel, in particular with ultrasonic lithotripsy (see Fig. 5.35A). This offers the additional advantage that the stopcock on this port can be controlled with the hand holding the nephroscope sheath (see Fig. 5.36). If thick-walled silastic tubing and a sheath that rotates 360° around the instrument is used, space problems with the buttocks, or when the nephroscope is tilted steeply under the 12th rib, are avoided.

We prefer using the nephroscope with the purpose-built sheath rather than the Amplatz sheath. With some expertise in the manipulation of the in- and outflow, the collecting system can be distended as needed for optimum inspection without risking increased intrarenal pressures. With the Amplatz sheath the irrigation fluid continuously drains around the nephroscope, so that the collecting system is always collapsed and more difficult to inspect. With the Rutner sheath the outflowing irrigant is channelled and the field is not drenched, yet it does not permit so precise a control of the irrigation as with the complete nephroscope and sheath. Even with the best irrigation, intrarenal orientation and localization of the calculi by endoscopy alone may frequently be difficult. The possibility of fluoroscopic control during this manipulation is therefore mandatory, as it provides an extra dimension for establishing the topography of the nephroscope, the calculi, the safety guidewire and the ureteral catheter to each other.

Although experimental studies (Webb & Fitzpatrick 1985a) suggested minimal trauma to the kidney even from larger nephrostomy tracts, we routinely use nephroscopes with a 24 F or 27 F sheath. The thicker instrument is mainly utilized for borderline extraction stones in the range of 6–8 mm in diameter. Modified nephroscopes with an 18 F sheath are available for nephroscopy in situations where a thinner tract appears more advisable, e.g. for inspecting a calyceal diverticulum to advance a guidewire under vision down its connection to the collecting system. Recently an 18 F paediatric nephroscope has become available that has all the properties of the standard universal nephroscope at smaller dimensions (Fig. 5.32). A sonotrode as used for short ureteroscopes (see Ch. 6, Fig. 6.10) or a 3.5 F electrohydraulic probe can be used down its straight working channel, as well as a variety of straight rigid forceps. Occasionally the correct position of a neprostomy tract cannot be decided from fluoroscopic orientation only, e.g. when a stone-bearing peripheral calyx has to be punctured directly. In this situation we have found a 12 F miniature nephroscope endoscope most helpful, the sheath of which slides smoothly over the 9 F telescope dilator (see Fig. 5.32).

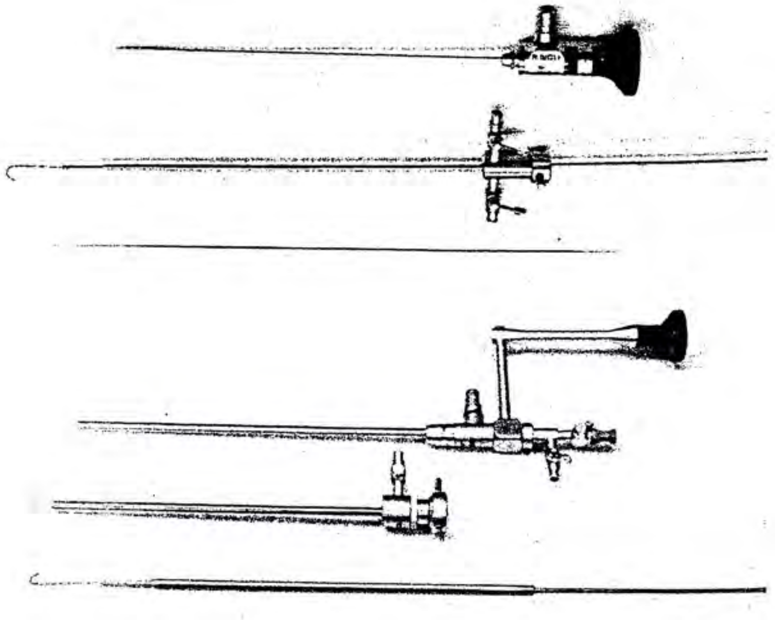


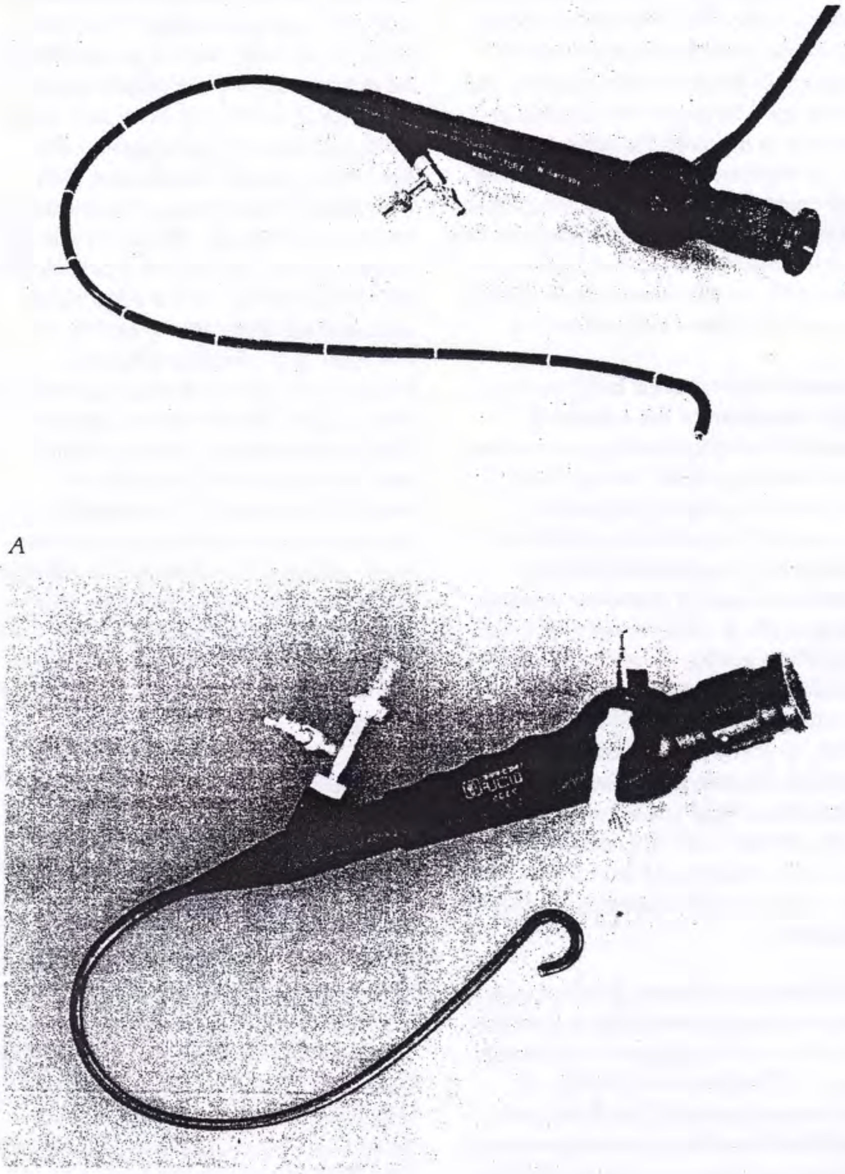
Fig. 5.32

Miniature nephroscopes (Wolf): 12 F nephroscope without working channel, the sheath of which is inserted over the 9 F telescope dilator, and paediatric 18 F nephroscope, the sheath of which is inserted over the 15 F dilator.

Flexible nephroscopes

In 1975, Harris et al reported on the first use of a fibreoptic bronchoscope for extracting residuals after stone surgery through a nephrostomy, and flexible nephroscopy has since received continuous interest. The obvious advantage of this approach lies in the possibility of guiding a rather thin instrument under optical and fluoroscopic control through tortuous tracts and to remote areas of the kidney that cannot be reached with a rigid instrument.

Originally flexible endoscopes designed for other organs were used, in particular choledochoscopes, but a variety of purpose-built flexible nephroscopes are available today (Fig. 5.33). Varying from a length of 50 cm to 70 cm and an outer diameter of 15 F to 18 F, the tips can be flexed upwards 100°–180° and downwards 30°–130°. The deflector length varies from 25 mm to 35 mm (Clayman & Casteneda-Funiga 1984). All instruments provide an instrumentation port 2–2.6 mm in diameter, most incorporate a locking feature to stabilize the flexed tip in a certain position and are fully immersible for sterilization. They can be locked watertight into the sheaths of rigid nephroscopes, either with a metal connector or a rubber-shod connector. The length of flexible endoscope protruding from the working side of the nephroscope can be adapted to the individual situation (Marberger 1983b, Korth 1984). Irrigation is accomplished via the working port. The use of a nephroscope sheath or a nephrostomy sheath permits continuous flow irrigation; an 18 F instrument with two irrigation taps even provides simultaneous inflow and outflow through the flexible instrument itself. A wide array of flexible baskets, triradiate graspers, diathermy, cutting coagulation and 3.5–5 F electrohydraulic probes are available as surgical accessories.


A

B

Fig. 5.33
(*A* and *B*) Flexible endoscopes: 16 F Storz (top), 16 F Wolf (bottom); for 15 F Olympus nephroscope, see Figure 8.14.

Most urologists are not accustomed to working with a flexible endoscope so that its use must be practised before engaging in flexible nephroscopy. One hand is used to steady the flexible instrument as it enters the nephrostomy tract or nephroscope sheath, the other hand controls the deflecting mechanism and the locking lever. By supinating this hand the instrument can be rotated by about 180°, so that theoretically every point of the kidney can be reached.

Intrarenal orientation is facilitated by slight distension of the collecting system by limiting the irrigant outflow and increasing inflow; we routinely pressurize the irrigant bag with a pressure cuff, as used for rapid blood transfusions. A guidewire directed towards the area of particular interest and an ureteral catheter are important orientation guides; fluoroscopy and repeated dye injection for correlating the topography of the collecting system to the tip of the nephroscope is essential. Flexible nephroscopy is more difficult than rigid endoscopy, and ample training with the instrument in the lower urinary tract is recommended before the technique is employed within the kidney.

In the hands of experts, flexible nephroscopes have proven highly versatile and effective for all types of intrarenal surgery (Clayman et al 1984b). All instruments presently available have significant drawbacks in comparison to rod-lens nephroscopes. Even with the best fibre bundles the optical qualities are significantly poorer both in respect of resolution and illumination. Urologists are spoiled by the brilliance of modern rigid endoscopes and the grit-like haze on the image caused by the arrangement of the fibre bundles is initially most annoying. With the entire port available for irrigation, adequate flow rates for good visibility can usually be attained, especially with pressurized irrigation.

The insertion of an instrument into the port, for example a basket to extract a calculus, virtually abolishes irrigation in all instruments with channels smaller in diameter than 6 F. But even with larger ports and pressurized irrigation, the flow rate is usually insufficient with even slight haemorrhage. Orientation is therefore extremely difficult in acutely dilated tracts. The narrow working port also limits the size of the instruments available for stone manipulation; the branches of 5 F flexible alligator forceps only permit the engagement of calculi up to about 5 mm in diameter. Finally, instruments in the working port also reduce the flexibility of the tip by at least 20°. Frequently a calculus in a remote calyx can be seen with the flexible instrument, but the tip has to be deflected to insert an appropriate grasping instrument. It may then prove impossible to re-enter the calyx due to the reduced manoeuvrability of the tip.

In our experience, at least 95% of all percutaneous stone manipulations can be performed with rigid nephroscopes. The availability of pain-free piezo ESWL (Marberger et al 1987), the trend towards multiple nephrostomy tracts rather than extensive intrarenal manipulation, and the development of miniature nephroscopes (Marberger 1987) are further reducing the need for flexible instruments. Nevertheless, in selected cases, they may ultimately decide between failure and success (see Figs. 5.48, 9.18). In spite of their technical complexity, high costs and fragility, they should therefore be available at endourological centres, especially as with continuous practice their efficiency increases sharply. The technology of this field is in rapid flux and new developments like the availability of miniature chip cameras, or of low-priced, extremely thin image-bundles may promote flexible endoscopy in the upper urinary tract in the near future.

PERCUTANEOUS STONE EXTRACTION

Percutaneous extraction of an intact renal calculus via a nephrostomy tract is the most satisfactory method of percutaneous stone manipulation. There is an extremely low risk of residual fragments, the technique is simple, it does not require sophisticated stone disintegration techniques and it is rapidly performed with minimal morbidity (see Table 5.2). There can be no doubt that it is the treatment modality of choice wherever applicable, provided ESWL is not available. The only limiting factor is a disproportion between the size of the calculus and the diameter of the tract respective to the sheath it has to be removed through.

Although we are reluctant to dilate nephrostomy tracts over 27 F, experimental and clinical data suggests that blunt dilatation to about 34 F is acceptable both from the damage caused to the renal parenchyma and the complication rate. It therefore appears justified to attempt to extract any calculus that will pass through a 34 F tract, i.e. up to a diameter of about 1.1 cm. The alignment of the stone along its longest axis in the direction of the forceps, with jagged ends preferably covered by the grasping branches, is most important.

The size and type of the grasping instrument used likewise limits the size of the calculus that can be managed by extraction. Grooved Randall or Mazzariello-Caprini forceps worked under fluoroscopic control permit manipulation of large stones (Clayman et al 1983a), but because of the lack of endoscopic control they carry a high risk of renal damage and should therefore not be used routinely. Baskets are difficult to use in non-tubular systems as the stones tend to elude engagement; special floppy, flush-ending, four-wire baskets are more effective, but also usually fail with stones larger than 1 cm in diameter. The length of the branches of alligator forceps in millimetres corresponds to the maximum diameter of a calculus that can be grasped with the instrument. Flexible three-prong graspers have a wide-opening angle and are therefore more effective, but their branches are difficult to see and tend to get hooked in the renal parenchyma and cause bleeding. The rigid panendoscopes designed for the lower urinary tract permit the use of large flexible forceps, but even these are too small for most symptomatic stones. Rigid stone forceps introduced into cystoscopes protrude too far from the tip of the endoscope to be utilized safely within the confined space of the renal pelvis. The solution to this problem is the insertion of rigid forceps through purpose-built rod-lens nephroscopes.

A variety of instruments of the alligator two-prong, triradiate or three-prong type are available. When used through the nephroscope the stone is usually rapidly identified and engaged, but in general it is too large to be extracted through the working port. By extracting it together with the nephroscope through the sheath, calculi up to 8 mm in diameter can be extracted. Three-prong rigid forceps with spring-loaded handles are ideal for this approach because the prongs open completely within 1.5 cm from the tip of the nephroscope (Fig. 5.34), engage the calculus securely and forceps and nephroscope can be extracted with one hand while the sheath is stabilized with the other. Alligator forceps open within 1 cm of the tip of the nephroscope, but the calculus that can be grasped firmly is limited to a maximum diameter of the length of the branches. They are therefore used for smaller stones or calculi in narrow confinements, where three-prong graspers need too much space to open. They are also employed to remove matrix or clots, if these materials cannot be aspirated. Two-prong forceps, opening with almost parallel jaws, have to be advanced by at least 2 cm from the tip of the nephroscope to open. As the jaws are clearly seen through the nephroscope they can then be slipped over a calculus without opening much more than the maximum diameter of the calculus. They are therefore particularly helpful for extracting calculi wedged into the ureteropelvic junction or the ureter. When the nephroscope is used in combination with a nephrostomy sheath, even larger stones are amenable to extraction. Calculi up to 1.1 cm in diameter pass through the 34 F Amplatz sheath, which protects the renal tissue, reduces haemorrhage and facilitates repeated reinsertion of the nephroscope.

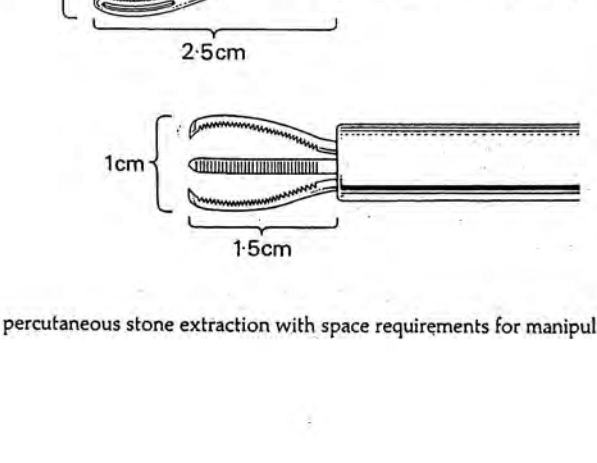


Fig. 5.34
Stone forceps for percutaneous stone extraction with space requirements for manipulation.

In view of the risk of residual fragments after stone disintegration, it is tempting also to extract stones slightly too large to pass through a sheath by simply grasping them with strong forceps and extracting them together with the sheath. The safety guidewire is then used for regaining percutaneous access. Although feasible, the calculus frequently slips out of the forceps at the level of the renal or lumbodorsal fascia, where it is then lost along the tract. Although there is no clinical evidence available that it acts as a nidus for a perirenal abscess, the appearance of this 'residual' stone on follow-up films is at least annoying to patient and doctor. Most of the lost stones can be retrieved by entering the tract again under visual control along the safety guidewire and by attempting to grasp the stone again with forceps or by a cut-down on the stone, but we no longer remove stones in this manner.

The development of a special optical triradiate grasper by Miller and Wickham (1984) reduced the risk of losing the stone during extraction: special triradiate graspers with powerful jaws that provide a vice-like grip securely engage the stone so that calculi up to a diameter of 1.5 cm can be extracted intact together with the instrument and the sheath. Extraction is performed under fluoroscopic control and by gently turning the instrument to adapt to the tissues as resistance is encountered.

Incision of the lumbodorsal fascia with a knife at the time of tract dilatation facilitates the procedure. The mechanical trauma to the tissue surrounding the tract is naturally greater, as reflected by more significant haemorrhage after the extraction. Provided the upper-limit of 1.5 cm stone diameter is respected, the method seems to be safe and highly effective. Larger calculi can also be forced through the tract, but this tends to split the renal tissue and may result in significant vascular damage (Smith & Lee 1983). Stones with a very jagged contour tend to get hooked in the fascia and subsequently may be lost; they are usually amenable to ultrasonic disintegration, so that this approach is preferable. This also applies to soft stones, which are often crushed by the powerful jaws of the grasper during extraction.

The free availability of ESWL has today greatly diminished the number of patients subjected to percutaneous extraction of small stones. The elaborate techniques designed in the early 1980s to remove these stones from poorly accessible areas of the kidney are today virtually obsolete, in particular with the introduction of pain-free ESWL, which can be utilized to remove any peripheral stone fragment left behind after an endoscopic procedure without needing anaesthesia. Most stones subjected to percutaneous stone manipulation today are too large for extraction. Nevertheless, extraction techniques are still indispensable for removing larger fragments during disintegration, in particular after electrohydraulic lithotresis, and for removing stones from obstructed systems.

INTRARENAL STONE DISINTEGRATION

Mechanical disintegration

The disruption of urinary calculi by mechanical crushing requires considerable force with the risk of trauma to the surrounding structure, so that it is practically limited to the treatment of bladder calculi. The size requirements a double-jaw lithotrite has to meet in order to provide adequate strength and efficiency prevents its use through a nephrostomy tract. The 'punch' technique significantly reduced the size-requirements of these instruments, as the calculus is broken up mainly by shearing forces (see Ch. 6). This provides space for an irrigation system and an integrated sheath, within which the lithotrite is worked and the calculous debris is removed without injury to the surrounding tract. Although developed for bladder calculi, the Mauermayer–Punch lithoclast has been employed through percutaneous nephrostomy tracts (Smith et al 1982). Korth (1984) promotes a modified version for intrarenal surgery that can be used through a standard nephroscope sheath.

Regardless of the type used, the instrument acts by counteracting movement of the lithoclast cylinder against the sheath over a distance of at least the length of the lithoclast window, i.e. at least 2 cm, plus the length of the reinforced lithoclast tip distal to the window. This requires a spacious collecting system, which in our experience, is only rarely available when renal calculi are present. To reduce mechanical movement the stone window can be minimized, but this also reduces the size of calculi that can be disrupted with this technique, as they have to fit into the window with at least one major segment. Finally, with the lithotrite advanced vision is severely impaired to a barrel-type view. With a good continuous flow system the collecting system may fold up between sheath and lithotrite window without this being noticed. A punch-type lesion of the pelvis may result, which is considerably larger than with simple perforation and therefore more serious. Although most nephroscope producers also provide purpose-built punch-lithoclasts, they are only rarely used for percutaneous manipulation.

Ultrasonic lithotripsy

Attempts to overcome the structural adhesive properties of urinary calculi by exposing them to ultrasound of high frequency failed (Mulvaney 1953, Coats 1956). By changing the concept and using ultrasound only to propel a steel probe to high frequency sinus vibrations, urinary calculi may be disintegrated by a drill-like action. Longitudinal and transverse vibrations result in a jackhammer impact of the probe on the stone, which disintegrates to sand at the contact site. With ultrasound of 20–27 kHz all urinary calculi may be disintegrated with instruments of this type, provided the probe remains in contact with the stone and the stone debris is removed continuously. Lutzeyer et al (1970) and Gasteyer (1971) solved this problem by using a hollow sonotrode and connecting its central lumen to a vacuum pump which aspirates the stone dust continuously, together with the irrigation fluid, and cools the probe. Their prototypes later became commercially available as lithotrites for vesical calculi and have been in clinical use for this purpose for over a decade.

In 1977, Kurth et al and Rathert et al (1977) used instruments of this type to disintegrate renal calculi via the tract of a pre-existing U-tube nephrostomy. Alken et al (1981) subsequently extended the approach to the treatment of kidney stones via a percutaneous nephrostomy. Vesical lithotrites, however, proved to be too awkward and cumbersome for intrarenal lithotripsy, and purpose-built ultrasonic

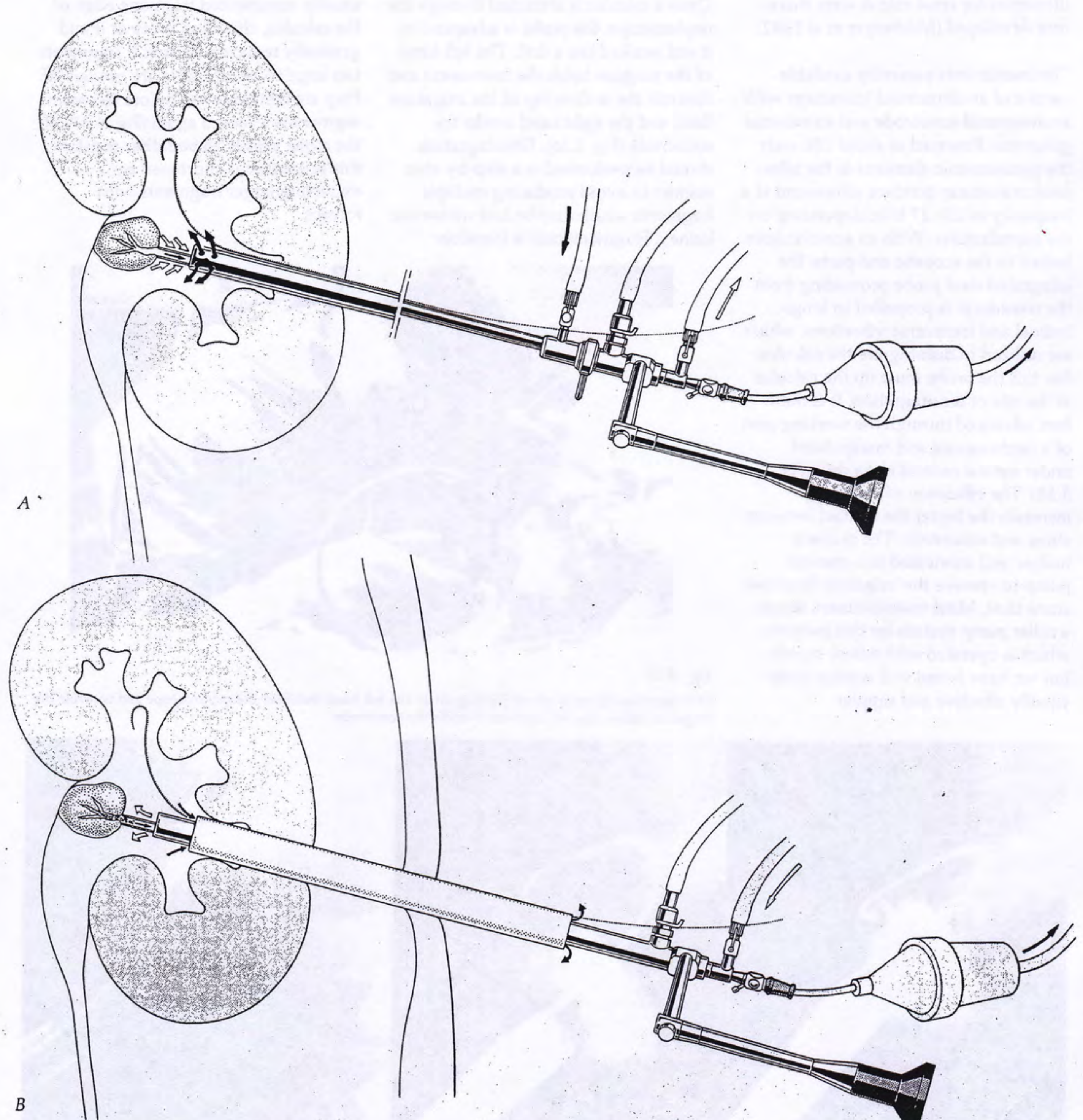


Fig. 5.35

Percutaneous ultrasonic stone disintegration. (*A*) Nephroscope sheath with a closed, continuous flow irrigation system: using the working channel as an outflow port (open arrows) keeps the fragments around the tip of the sonotrode, even if the latter is clogged. (*B*) Open system with a nephrostomy sheath: debris is flushed out continuously alongside the nephroscope, but it is more difficult to keep the fragments around the probe and orientation is more difficult because the collecting system tends to be completely collapsed.

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lithotrites for renal calculi were therefore developed (Marberger et al 1982).

The instruments presently available consist of an ultrasound transducer with an integrated sonotrode and an external generator. Powered at about 100 watt the piezoceramic elements in the ultrasonic transducer produce ultrasound at a frequency of 23–27 kHz, depending on the manufacturer. With an acoustic horn bolted to the acoustic end-parts, the integrated steel probe protruding from the transducer is propelled to longitudinal and transverse vibrations, which are utilized to disintegrate the calculus. For this the probe must tip the calculus at the site of disintegration. It is therefore advanced through the working port of a nephroscope and manipulated under optical control like a drill (Fig. 5.35). The efficiency of the probe increases the better the contact between stone and sonotrode. The probe is hollow and connected to a vacuum pump to remove the irrigation fluid and stone dust. Most manufacturers supply a roller pump system for this purpose, which is operated with a foot-switch, but we have found wall suction to be equally effective and simpler.

Once a calculus is identified through the nephroscope, the probe is advanced to it and worked like a drill. The left hand of the surgeon holds the instrument and controls the in-flow tap of the irrigation fluid, and the right hand works the sonotrode (Fig. 5.36). Disintegration should be performed in a step-by-step manner to avoid producing multiple fragments which may be lost within the kidney. Fragmentation is therefore usually commenced from one edge of the calculus, chiselling away at it and gradually reducing its size. If fragments too large to be aspirated are broken off, they are first removed before the main segment is attacked again (Fig. 5.37). If the stone proves to be rather resistant, this procedure is shortened by extracting larger fragments with forceps.

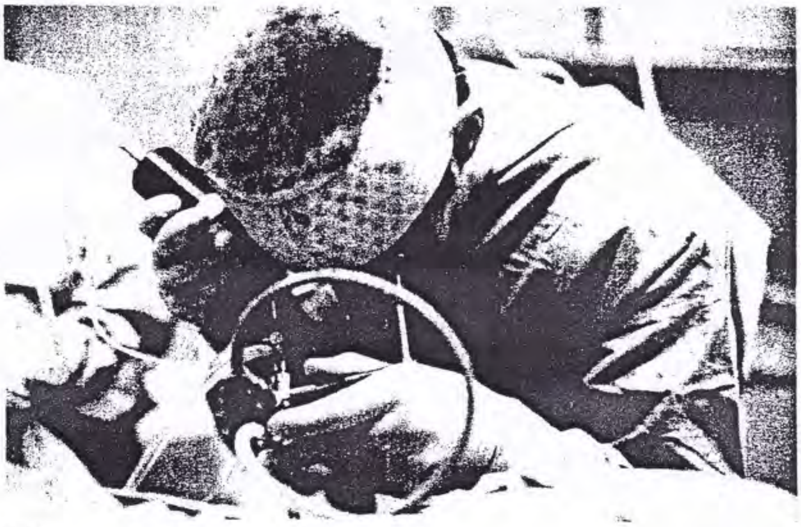
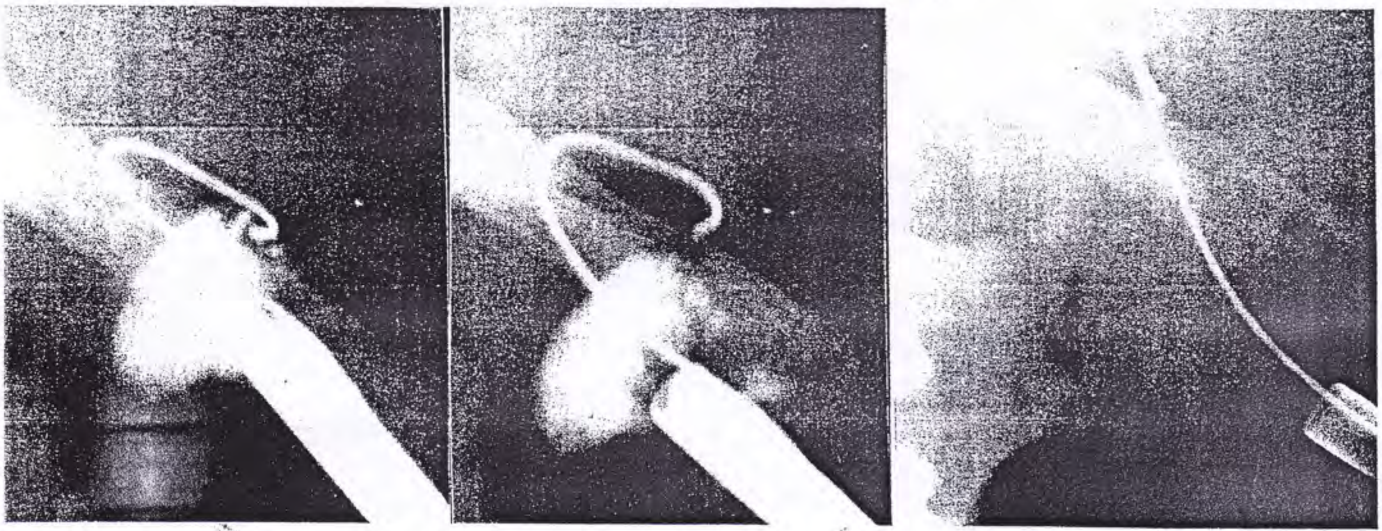


Fig. 5.36

Percutaneous ultrasonic stone disintegration: the left hand stabilizes the nephroscope and controls the irrigation inflow tap, the right hand works the sonotrode.



A *B* *C*

Fig. 5.37

(*A–C*) Step-by-step reduction of stone by ultrasonic disintegration, with continuous removal of fragments as they are produced.

During the entire manipulation it is most important to avoid a flow of irrigation fluid away from the probe to prevent spillage of calculous material through the kidney. This is best achieved by continuous aspiration during lithotripsy. As the probe may be clogged from stone debris, we prefer to use the working port as the outflow port and the space between nephroscope sheath and nephroscope as an inflow port (see Fig. 5.35A). Although in this manner the irrigation fluid in the immediate vicinity of the endoscope is bloodier and vision therefore poorer, all stone fragments are reliably kept in sight around the tip of the nephroscope.

Good contact between sonotrode and stone promotes fragmentation. As the latter decreases in size, it may be pushed away from the surgeon into a poorly accessible calyx. The stone should therefore be trapped during disintegration in an accessible part of the collecting system, for example the ureteropelvic junction. If the stone threatens to disappear into the infundibulum of a poorly accessible calyx, disintegration is interrupted and it is retracted into the renal pelvis with forceps.

Fluoroscopic control is mandatory, preferably with the possibility of magnification and a freeze-image. With an unclear situation a plain film is obtained, and this is always necessary before terminating the procedure to rule out residual stones. Endoscopic inspection alone is absolutely insufficient for this purpose.

Complete removal of all residuals is always attempted. With a well-functioning continuous flow irrigation system, smaller fragments can usually be aspirated using the sonotrode like a vacuum cleaner. Calyceal residuals are localized by combining fluoroscopy and endoscopic inspection; occasionally the collecting system has to be distended to identify the infundibulum of a side calyx by shortly kinking the tubing of aspirator and outflow channel. With a properly placed nephrostomy tract, most calyces can be reached. We have given up attempts at flushing a residual fragment from a remote calyx with steerable angiography catheters, as it is extremely time-consuming and, at least in our hands, was not very successful. Likewise we do not use forced irrigation on the nephroscope or nephroscope sheath, for example, with an Ellik evacuator.

If a stone-bearing calyx cannot be reached via the existing nephrostomy tract, it is punctured directly under fluoroscopic control. Larger stone fragments can frequently be tipped with the needle and pushed back into sight (Fig. 5.38). Otherwise, a 7 F angiography catheter is inserted and rolled up into the stone-bearing calyx. With the nephroscope shaft in place in the original tract, an attempt at flushing the stone into the pelvis is undertaken. If this is not successful, the tract is dilated and the paediatric nephroscope is inserted and the stone removed either with stone forceps or with a 5 F sonotrode. If this fails, or the calyx cannot be punctured, the residual stone has to be removed with a flexible nephroscope. As, by this time, there is usually some haemorrhage in one-stage sessions, it is better performed in a separate stage, at least 24 hours later. Lately, we have resorted to pain-free piezo-ESWL. The small fragments can usually be picked up easily with the ultrasonic imaging technique of this method and the stone debris is rapidly cleared from the kidney via the nephrostomy tube, which is still in place.

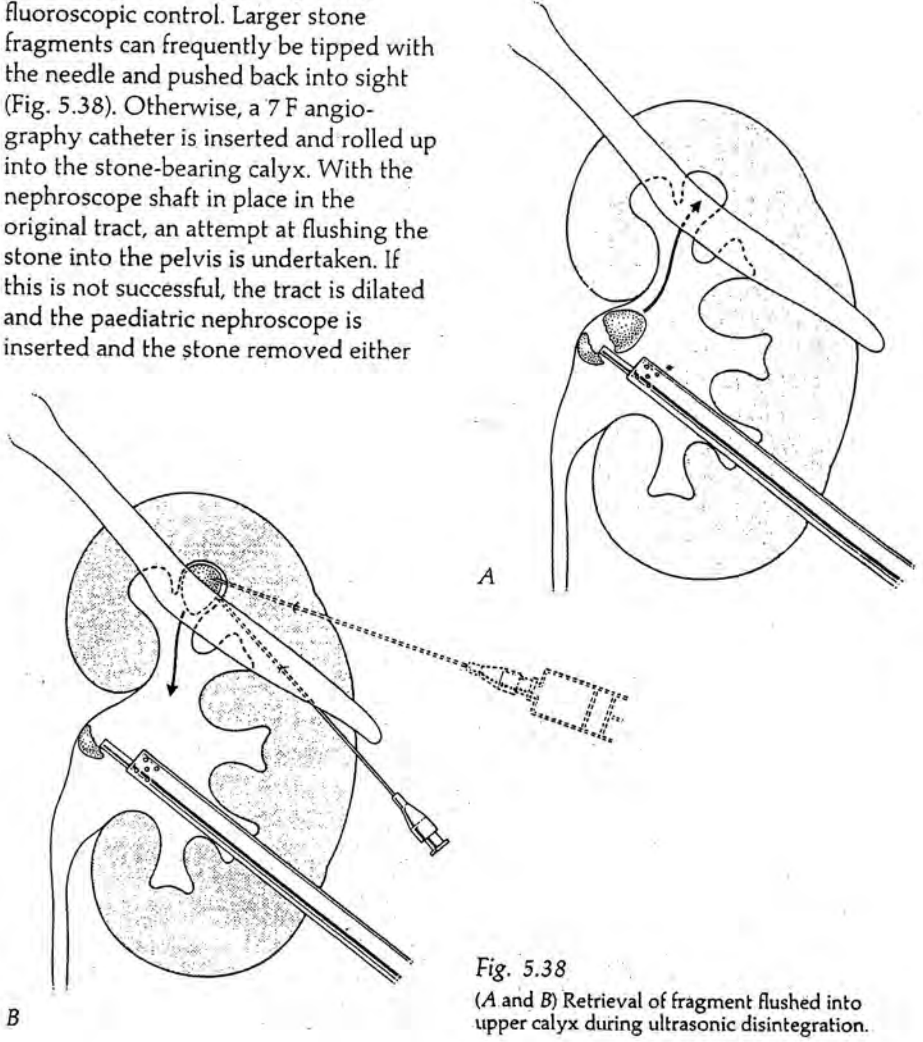


Fig. 5.38
(*A* and *B*) Retrieval of fragment flushed into upper calyx during ultrasonic disintegration.

The ureteral catheter usually prevents stone fragments from passing down the ureter during disintegration. If this occurs, a 4 F filiform basket is advanced down the ureter alongside the ureteral catheter, which is then removed. The basket is opened distal to all calculous material and then simply extracted back into the pelvis bringing up the fragments. The next procedure in the endourologist's armamentarium, antegrade ureteroscopy, only rarely has to be resorted to in this context.

In vitro, and theoretically also in vivo, all urinary calculi can be disintegrated with ultrasound. The time of energy exposure required for this mainly depends on the surface structure, hardness, density, porosity and, to a lesser extent, the chemical composition of the stone. In clinical practice very smooth and hard calculi, mainly uric acid stones and some calcium oxalate stones, may prove to be quite resistant. Based on in vitro studies, a baffle-plate loosely fitted to the tip of the sonotrode was thought to increase the drilling properties multifold (Terhorst et al 1972, 1975). Our clinical experience has not confirmed this and the experimental studies of Terhorst et al (1975) even suggest slightly more mechanical trauma by the jagged rim of the baffle-plate. In our experience with over 1500 patients subjected to ultrasonic lithotripsy, calculi were too hard for disintegration in only 3 patients; electrohydraulic lithotripsy likewise failed in these very smooth and round calcium oxalate monohydrate stones of particularly high density. Large stones, stones with a very smooth surface and very dense stones may occasionally require very long disintegration times of up to several hours. We prefer to reduce this time by supplementing ultrasonic lithotripsy with electrohydraulic fragmentation or by extracting larger fragments. Good contact between probe and stone is imperative for successful ultrasonic disintegration. Pebble-shaped, very dense and round stones, occasionally cannot be stabilized sufficiently to exert enough pressure on them with the sonotrode. As they escape, the sonotrode may perforate the collecting system (Fig. 5.39), or the calculus can be pushed to a region of the kidney where it cannot be reached again. In these patients we prefer to use electrohydraulic lithotripsy, preferably with a percutaneous coagulum technique. Once the surface is broken up, most calculi apparently resistant to ultrasonic disintegration can be fragmented very rapidly.

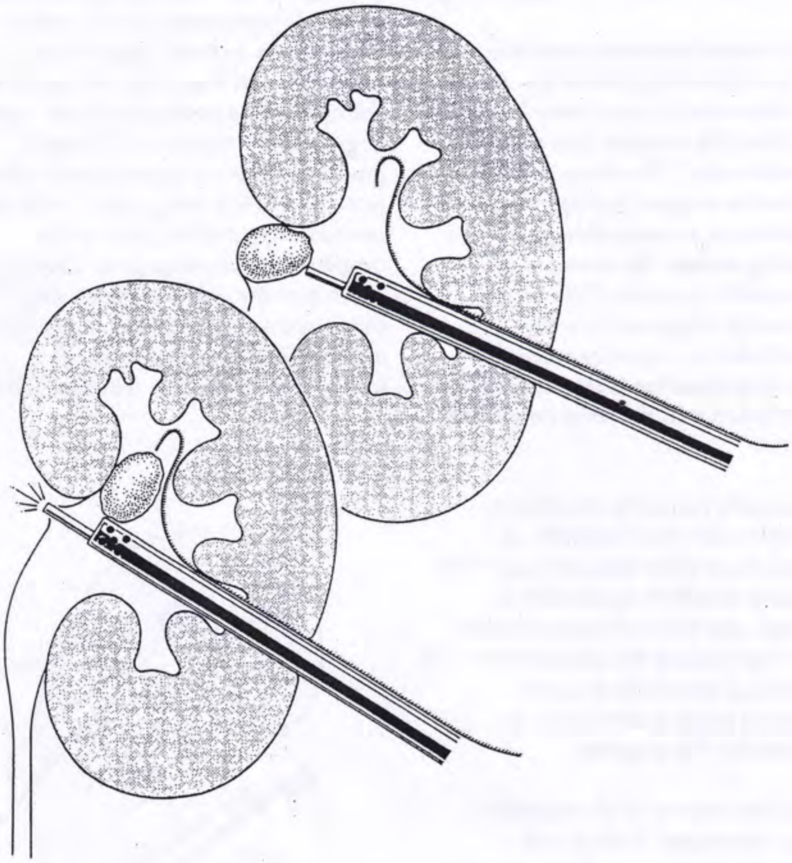


Fig. 5.39

Perforation of the renal pelvis as sonotrode slips off a smooth stone.

The main advantage of ultrasonic lithotripsy lies in its minimal adverse effects on surrounding soft tissues. The maximum sound intensity at the tip of a sonotrode is $< 0.35\ W/cm^2$, and decays rapidly within millimetres from the tip, especially in oblique directions, or with interposition of a calculus (Marberger et al 1985b, Fig. 5.40). As even under optimum conditions the cavitation threshold for ultrasound at this frequency is at least $0.7\ W/cm^2$ (Lehmann et al 1978), cavitation does not occur during ultrasonic lithotripsy. There has been speculation that ultrasound may cause DNA breakdown by mechanisms other than cavitation, but sister chromatid exchange rate studies of human leucocyte cultures (Marberger et al 1985b) and analyses of the DNA of rat kidneys (Wickham & Miller 1983) subjected to ultrasound of this type failed to provide any evidence for this. Stone disruption is achieved purely by mechanical forces due to the oscillation of the probe. Direct contact of the probe with rabbit bladders and continuous ultrasound exposure over 5 minutes at maximum generator setting (Wolf ultrasonic lithotriptor) and transverse vibration amplitudes of the probe $< 30\ \mu$ and longitudinal vibration of $< 50\ \mu$ causes only slight mucosal abrasion and submucosal haemorrhage and oedema. It only slightly exceeds the damage caused by the probe connected to the vacuum pump only (Terhorst et al 1975, Marberger et al 1985b). As the sonotrode works like a drill, metal flakes may be chipped off the probe at the site of action, but even more at sites of contact between probe and nephroscope (Fig. 5.41). These metal residuals occasionally become visible during disintegration as they reflect light better than the surrounding mucosa. Animal studies show that they are washed out of rabbits' bladders within 24 hours when injected into the cavity and within 1 week when rubbed into the mucosa. When trapped within the bladder wall they remain unchanged within the musculature with minimal foreign body tissue reaction (Marberger et al 1985b).

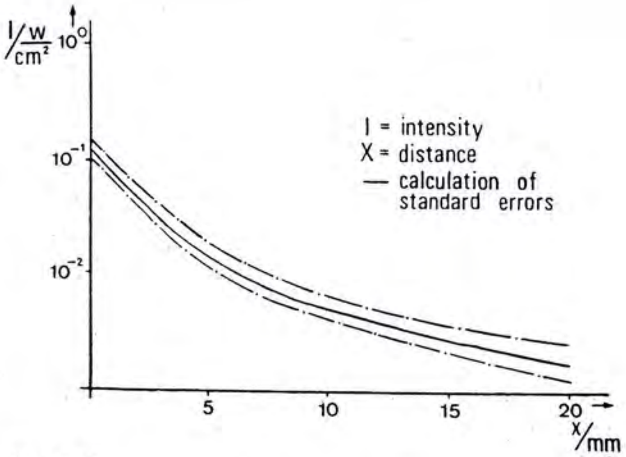


Fig. 5.40

Ultrasound intensity measured at the tip of five sonotrodes operated under water; the values measured in the axial antegrade direction off the probe are given as a function of distance from the tip of the probe (SEM) (reproduced with permission from Marberger et al 1985 World Journal of Urology 3: 27).

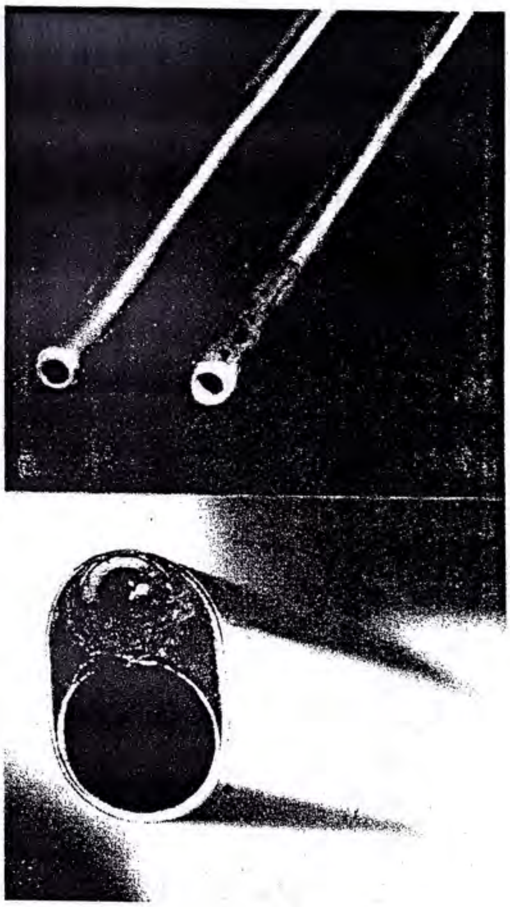


Fig. 5.41

Metal wear during ultrasonic lithotripsy: close-up view of new (left) and used (right) sonotrobes and tip of a nephroscope used for ultrasonic lithotripsy in 200 patients (reproduced with permission from Marberger et al 1985 World Journal of Urology 3: 27).

Apart from mechanical perforation, which may occur as with any other rigid instrument used percutaneously, thermal damage must be considered the only real potential hazard of ultrasonic lithotripsy. It develops at the tip of the probe as a linear correlation between the time of energy exposure and the ratio of density differences at acoustical interphases (Lehmann et al 1978). Without irrigation cooling, the probe reaches temperatures of over 40°C within seconds, so that it should never be operated in this manner. Water cooling reliably prevents this. Already the dissipating capacity of a cylinder of 10 ml water of 20°C slows the temperature increase to < 3°C after 30 seconds. With continuous irrigation with saline of 20°C and a flow > 20 ml/min, the bladder wall temperature in the leporine bladder model increases a maximum of 4°C at the site of probe contact after approximately 3 minutes of continuous energy exposure, but does not increase further (Fig. 5.42). As intrarenal endoscopy requires flow rates of at least 100 ml/min for adequate vision, thermic damage is reliably avoided under standard conditions (Marberger et al 1985). If the safety rule of vision and good irrigation is violated and the ultrasound worked blindly, without cooling and possibly also with mechanical trauma, thermal damage may occur.

The main drawback of ultrasonic lithotripsy lies in the inability to transport the disintegrating energy around curves. When the sonotrode bends and contacts the nephroscope, energy is transformed into heat at this point and lost at the tip. Contact of metal against metal causes a typical high-pitched tone, so that it is easily recognized. If lithotripsy is continued in spite of this the probe may fatigue at this point and may even break off. Simple readjustment of the nephroscope and sonotrode eliminates the problem. Constant use wears down the instruments. In general, sonotrodes have a lifetime of 200–300 procedures. Some manufacturers today produce exchangeable sonotrodes, which are bolted to the transducer by the user. The continuous vibrations of the instrument puts special strain on the watertight casing of the sonotrode and optical systems. Gas sterilization therefore significantly prolongs the lifetime of the instruments.

Sonotrodes worked without irrigation, or in metal contact, are quite loud, and there has been considerable concern as to possible hearing damage to the surgeon's ear closest to the probe. We measured airborne sound levels in the 3-octave band centred on a frequency of 16 kHz from 72– 92 dB and at 20 kHz from 95–107 dB. Although these levels have not been shown to cause objective complaints, tinnitus, headaches and fatigue have been reported after exposure to these levels for an entire working day (Acton & Carson 1967). Legal exposure limits have not been defined internationally and vary from 75 dB to 90 dB for the 3-octave band centred at 16 kHz for industrial settings, with exposure for an entire working day. Although this rarely occurs under clinical conditions, protection of the ear closest to the probe with an earmuff appears advisable. This provides an attenuation factor of 10–15 dB, so that even subjective discomfort is eliminated. There is no need for protection on the contralateral ear, or the ears of the patient and other medical staff. There has also been some concern about a possible injury to fetal hearing when ultrasonic lithotripsy is utilized in pregnant women. As the waterborne sound intensity levels at the tip of the sonotrode are < 0.35 W/cm², any risk in this respect appears unlikely. It is rather the need for fluoroscopic control that contradicts the use of percutaneous manipulation during pregnancy.

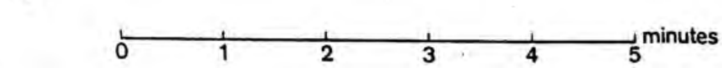


Fig. 5.42

Temperature in the bladder wall of rabbits in immediate vicinity of sonotrodes activated continuously directly against the mucosa in vivo (reproduced with permission from Marberger et al 1985 World Journal of Urology 3: 27).

Electrohydraulic stone disintegration
In 1950 the Russian engineer Jutkin (Goldberg 1969) discovered the destructive effect of electrohydraulic shock waves on solid bodies within a liquid medium. Goldberg and Rose (Goldberg 1969) applied the principle to the treatment of bladder calculi and designed an electrohydraulic lithotrite for disintegration of bladder calculi. Raney and Handler (1975) were the first to use the technique for disintegration of renal calculi under endoscopic control.

The stone is exposed to repeated bursts of hydraulic shock waves which are produced by high voltage, underwater discharges at the tip of a coaxial cable with an axial inner and tubular outer electrode (Fig. 5.43). This results in a short but steep pressure impulse with a large amplitude in the 500 bar range, which spreads spherically in water at a speed of 1500 m/s. The pressure curve rapidly decays from the point of discharge, so that the calculus must be approximated to the probe. The pressure front of the impulse is partially reflected by the calculus, resulting in a rebound phase and subsequently in additional high strain forces and cavitation phenomena within the stone. The stress resistance of the stone exceeds its strain resistance 100-fold; although both stress and strain disintegrate the calculus, the stress forces are more effective.

The equipment consists of the pulse generator, the electrodes and their extender cables, and the foot-pedal to activate the probe. The first model, the Soviet URAT 1, permitted pulse voltages to a maximum of 3 kV with an impulse current of a minimum of 500 ampere and a pulse duration of 1–5 ms, with a repetition rate of 30–100 Hz. The energy thus supplied suffices to disintegrate all urinary calculi, the time required for complete disintegration depending mainly on the chemical composition, surface, size and porosity of the stone as well as the proximity between probe and stone. Uric acid and oxalate stones are usually more resistant than calcium phosphate calculi (Marberger 1979), but electrohydraulic lithotripsy is far more efficient than any other physical method for stone disintegration.

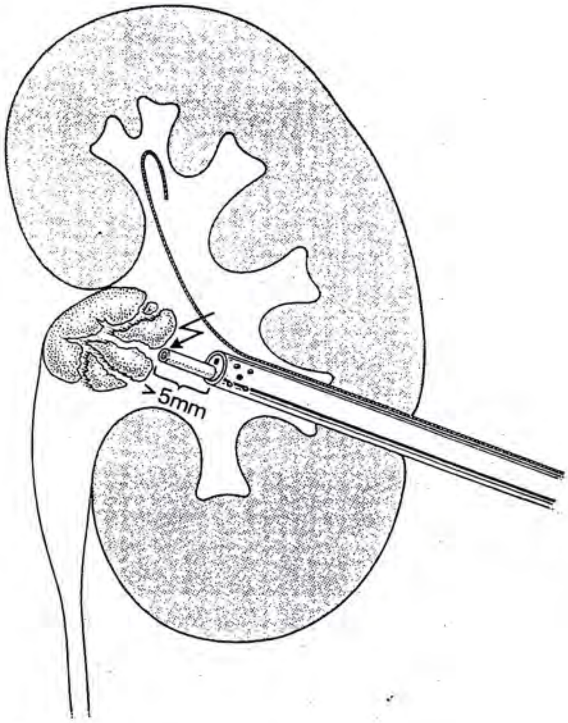


Fig. 5.43
Percutaneous electrohydraulic lithotripsy.

Unfortunately any tissue within 5 mm of the point of discharge is likewise hit by the full impact of the shock wave. In soft tissues like the renal pelvis this may result in disruption of the tissue integrity, sloughing and oedema of the adjacent structures, an effect very similar to the blast effect of an explosion (Terhorst et al 1975, Pelander et al 1980, Nasr 1982). Heat obviously also plays a role (Purohit et al 1980), but the damaging effect is further increased by calculous fragments which are blasted off the stone and impacted shrapnel-like on underlying surfaces (Webb & Fitzpatrick 1985b). These hazards are easier to avoid by an improved triggering mechanism of the discharges and better modulation, providing extremely steep impulse curves of extremely short duration. Newer lithotrites (Fig. 5.44) therefore provide pulses at various power levels, the frequency of which can be modified in an ungraded range of 1 ('single-shot') to up to 70 per second and the duration of which can be adjusted between 1 and 5 seconds (Raney 1975, Bülow & Frohmüller 1981). This permits the use of higher energy up to a maximum discharge of 8 kV. Electrodes 1.8–9 F in diameter are available today. As they are flexible, the thinner electrodes can be used through the miniature nephroscope or flexible nephroscopes and they can therefore be utilized to disintegrate stones in remote calyces not amenable with the standard nephroscope.

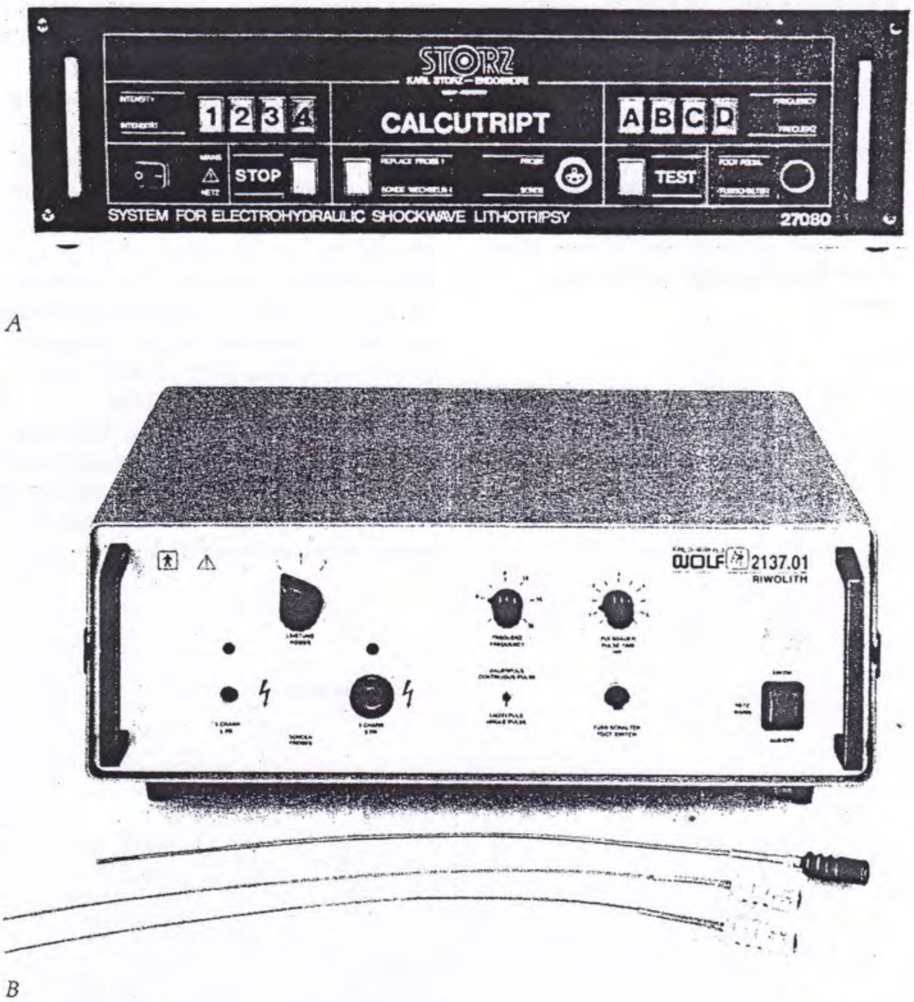


Fig. 5.44

Generators for electrohydraulic lithotripsy: (*A*) Storz (electrodes 3–9 F, maximum pressure 1020 bar) (*B*) Wolf (3.3–9 F electrodes, maximum pressure 1270 bar).

With the patient positioned and draped as usual, the calculus is approached with the standard nephroscope. Once it is clearly identified, a 9 F electrode is advanced down the working port to the calculus. Optical control of electrohydraulic lithotripsy is imperative at all times. The tip of the electrode must be within 1 mm of the calculus, but at least 5 mm away from all soft tissues and the endoscope, which may otherwise also be shattered. A 1/16 to 1/10 normal saline solution at room temperature has been recommended for irrigation to achieve an optimal spark discharge (Clayman & Castaneda-Funiga 1984). It can be obtained by simply adding 1 litre of normal saline to a 5 litre bag of sterile water. In clinical practice, however, we have not observed any difference in the efficacy of the probe when worked in normal saline. As the hypotonic solution should only be used during the disintegration phase, the irrigation fluid would have to be changed frequently and this is even more cumbersome when ultrasonic and electrohydraulic disintegration are utilized alternatively. We therefore use the same irrigation system and saline as for all other procedures.

The electrode is tipped against the stone at a part of the surface which appears irregular. Some authors suggest that the probe should have a film of 1 mm water between its tip and the stone for maximum efficiency, but again we have not found this necessary. The most important safety precaution is to see the tip of the electrode and the stone at all times, and to keep all other structures at least 5 mm away from the tip of the electrode (see Fig. 5.43). This is best accomplished if the stone is routinely tipped with the electrode. The electrohydraulic unit should first be set at a low-discharge voltage and at 'single-shot' discharge. The electrode is discharged by working the foot-pedal, and this is repeated with the probe in the identical position until the calculus breaks up. Voltage and discharge frequency are increased as needed. The objective is to fragment a larger stone into smaller segments in a step-by-step fashion, with the segments being removed as they are formed, rather than to reduce it to multiple difficult-to-remove fragments at once. In general, the calculus cracks rapidly. As soon as a larger fragment is formed, the probe is exchanged for forceps and the fragment is extracted. We have found it advantageous to remove first the finer calculous debris with an aspirator probe, or the sonotrode of the ultrasonic lithotrite. As the stone is reduced in size it becomes more difficult to shatter, as it may bounce away from the probe out of optimum range of the shock wave. To prevent this the surgeon may tend to press the calculus against the mucosa with the electrode at the time of discharge, but this should be avoided. Unless the calculus is extremely hard we prefer ultrasonic lithotresis at this stage of disintegration.

The insulation of the electrode rapidly wears down with use and the probe may then even be disintegrated itself. To prevent blasting foreign bodies into the kidney, it must therefore be discarded when the insulation is seen to recede at the tip of the probe during endoscopic manipulation. As 5 F electrodes have a lifespan of an average 20–30 discharges only, and this is even less for thinner probes, the 9 F electrode is preferably employed for stones amenable to the standard nephroscope. Thinner electrodes have to be used through ureteroscopes, miniature nephroscopes and the flexible nephroscope. This not only reduces the efficiency of electrohydraulic disintegration, but also the irrigation capacity of these very delicate instruments, so that the procedure becomes significantly more difficult because of poorer vision. This is most apparent with flexible endoscopes, which are in addition reduced in their deflection range at the tip by about 20°–30° due to stiffness of the electrode. Electrodes can be refurbished by grinding down the non-insulated exposed metal portion of the probe until it is flush again with the outer insulation (Clayman & Castaneda-Funiga 1984), but in our experience the probes then wear out even more rapidly.

The main attraction of electrohydraulic lithotripsy lies in its high efficiency. Stones are disintegrated far more rapidly than with ultrasonic lithotripsy and some authors (Wickham & Miller 1983) use it as their technique of choice for intrarenal stone disintegration. Although we also have not seen serious complications, the potential risks of electrohydraulic lithotresis are well-established from experimental studies (Terhorst et al 1975). Purohit et al (1980) noticed perforations of the canine ureter in 33–40% after intra-ureteral discharge and Webb and Fitzpatrick (1985b) reported similar results for the canine renal pelvis. Although this certainly only results from a violation of the safety precautions as pointed out above, the confined dimensions of the renal collecting system may render these difficult to meet. We therefore, at the present time, prefer ultrasonic lithotripsy as the routine technique for intrarenal stone disintegration. Some selected cases, in particular with very large calculi, very hard and smooth stones and larger stones positioned at the entry of a wide upper-pole calyx are better primarily managed with electrohydraulic lithotripsy. In the latter situation, the need for good contact between sonotrode and calculus frequently results in dislodgement of the stone into an upper-pole calyx, where it is difficult to be reached with a rigid instrument. Coating the calculus with gelatine prior to disintegration facilitates complete stone removal. Ideal is the availability of electrohydraulic and ultrasonic lithotripsy. Difficult calculi are first fragmented into larger pieces with electrohydraulic discharges and then reduced further and removed with the ultrasonic lithotrite. The aspirator of the latter instrument facilitates removal of the calculous debris.

Microexplosion lithotripsy
In 1977, Watanabe & Oinuma suggested the use of an explosion to disintegrate calculi, as this is a simple process with an efficient power to mass ratio with easy carriage to target organs. In extensive in vitro and in vivo studies they found lead azide in a dosage of 2 mg per 10 mm thickness of the calculus to be shattered to provide reliable disintegration, yet not cause soft tissue damage in an area distant to 7.5 mm from the point of discharge (Watanabe et al 1983). After designing special instruments, the technique was utilized in the bladder and via a percutaneous nephrostomy also in the renal pelvis. The technique must, however, still be considered experimental. At the explosion the stone fragments and surrounding tissues are sprayed with ionized lead and lead azide compounds, which are known to have a considerable toxic effect. Although Watanabe et al (1983) observed no increase of lead levels in red blood cells in their animal experiments, or signs of carcinogenesis in mutation rate studies in bacterial cultures contaminated with lead, the activation of toxic lead compounds certainly at the present time prohibits clinical use of this method in Western countries. The therapeutic width between an insufficient charge and an excessive explosive reaction appears to be limited. Stones break up irregularly and often larger fragments need additional microexplosions, which are then difficult to apply because of the reduced size of the stone. With improved explosives and the adaption of shock wave focusing systems as used for military explosions, the technique may, however, one day become useful (Miller 1985).

Stone disintegration with lasers
Urinary stones can be disintegrated effectively with Q-switched Nd: YAG lasers or pulsed dye lasers. The most obvious advantage of this approach lies in the possibility of disintegrating stones through extremely thin and flexible instruments. In spite of the high pressures generated by the shock waves resulting from the rise and collapse of the plasma bubble at the site of action, the focal area is microscopically small and lithotripsy therefore considerably more time consuming than with electrohydraulic or ultrasonic disintegration. As percutaneous access to the kidney with rigid, large calibre instruments rarely presents a problem and renal stones are usually larger than ureteral stones, laser lithotripsy is not routinely used within the kidney. Its main application lies in the disintegration of ureteral stones (see Ch. 6). In some rare situations, as in the transureteral treatment of a calyceal stone through the ureteroscope, the technique also has its merits in the kidney.

PERCUTANEOUS COAGULUM LITHOTRIPSY

Residual stone fragments scattered throughout the kidney may occur with any type of intrarenal stone disintegration, but we have encountered the problem in particular with electrohydraulic lithotripsy. Although this method is highly effective in shattering the stone, the method lacks a convenient way of removing the stone debris, like aspiration in ultrasonic lithotripsy. A coagulum formed around the stone theoretically prevents dispersal of the fragments and would facilitate complete removal.

Clots formed of blood derivates as used in coagulum pyelotomy carry a high risk of pulmonary embolism, clotting disorders (Watson et al 1983) and obstruction from residual clots, which renders their use in percutaneous surgery hazardous. We recently utilized a new gelatine for this purpose, which consists of a partially hydrolysed collagen formed of chemically identical protein chains with molecular rates of 25 000 to 300 000. It liquefies to the properties of plasma at 37°C, but turns to a clear gel of high-tensile strength at temperatures below 34°C which prevents the dispersion of stone fragments during electrohydraulic lithotripsy. Produced from porcine protein, the agent is non-toxic, chemically stable, easy to sterilize and reasonably priced. Similar gelatines are used for alimentary purposes, as plasma expanders, for haemostatic sponges and for medical lubrication purposes. When used for percutaneous coagulum nephrolithotripsy in dogs, we found no evidence for acute or chronic adverse effect, in particular in respect to renal damage, residual clots or pulmonary embolism (Hasun et al 1985).

The agent is commercially available and prepacked in sterile, ready-to-use syringes. After the calculus is identified through the nephroscope, a bag of saline cooled to 6°C in a commercial refrigerator is connected to the inflow port, 5–10 ml gelatine are now injected through a special teflon probe, which is advanced to the stone through the working port. With irrigation reduced to approximately 30–40 ml/min, the temperature within the collecting system drops rapidly to about 15°C. This suffices to change the gelatine to a solid clot that permits rapid and complete extraction of the stone after electrohydraulic stone disintegration. At a lower temperature the tensile strength of the clot would be better, but this requires higher flow rates that rapidly result in clogging of the nephroscope with the gelatine and an impaired vision. Rather than obtaining a complete cast of the collecting system with the clot, which is extracted in toto with the stone fragments, the calculus is simply coated with a layer of gel (Fig. 5.45). This retains all fragments, but does not impair vision or irrigation. Electrohydraulic disintegration is performed as usual. Repeated discharges of the probe generate heat that rapidly dissolves the gel around the probe. By continuing cold irrigation at a low flow rate this is limited to the immediate vicinity of the probe, so that optical control and stone contact are facilitated, but the clot still retains the fragments. The attenuation effect of the clot on the shock wave also smothers the blast effect on the mucosa and soft tissue damage appears to be less pronounced. The clot is dissolved within seconds by changing the irrigant bag to saline of normal room temperature.

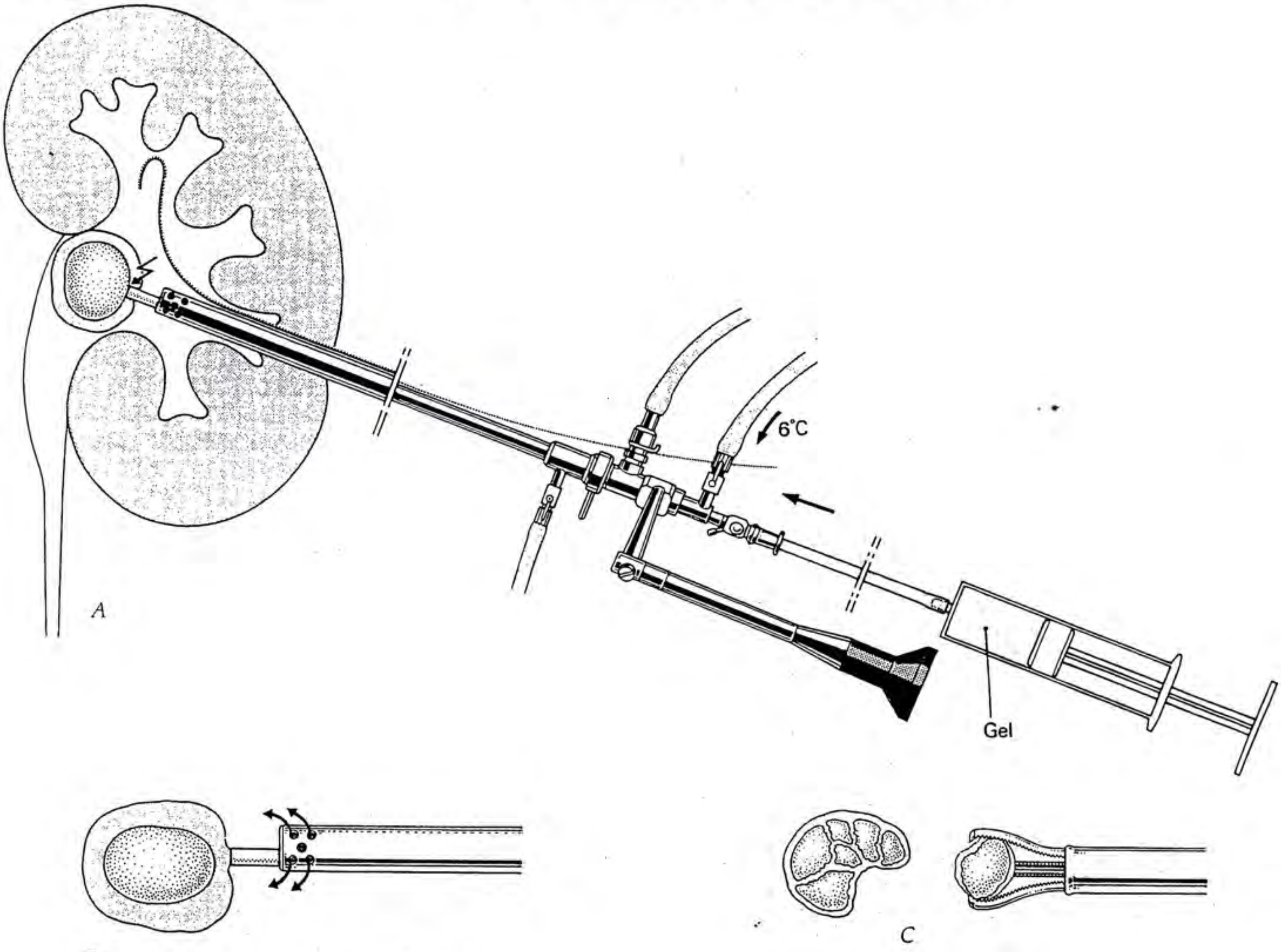


Fig. 5.45
(*A–C*) Percutaneous coagulum lithotripsy with thermolabile gel.

In a series of 18 patients subjected to electrohydraulic lithotripsy, Hasun et al (1985) found the technique to be highly effective and without any side-effects. Preliminary experience with the clot in ultrasonic lithotripsy exposed problems with the loss of efficiency of the sonotrode because of attenuation from the clot. Ultrasonic lithotripsy also relies heavily on aspiration through the probe for cooling and removal of stone debris, and the gel tends to clog the aspiration lumen. As the gel fills the collecting system with jelly-like masses, vision is also slightly reduced. In view of the more tedious technique, we therefore limit the use of coagulum lithotripsy to very hard, round and very smooth stones in a spacious collecting system; such stones are difficult to disintegrate even with electrohydraulic lithotripsy.

PERCUTANEOUS TREATMENT OF URETERAL STONES

In view of the high success rate and low morbidity of percutaneous stone manipulation it was a logical step to expand this approach to the manipulation of ureteral calculi (Fernström & Andersson 1977, Smith & Lee 1983). The dilatated ureter proximal to an obstructing calculus offers more space for endoscopic instrumentation than the collapsed segment distal to the stone, and it is certainly more direct to approach a stone in the proximal ureter through the abdominal wall and kidney, than through the entire lower urinary tract, and the distal two-thirds of the ureter.

The approach can only be utilized if the angle between the nephrostomy tract and the course of the ureter is 90°, or preferably more. The standard nephrostomy tract through a posterior calyx of the lower pole forms a more acute angle to the course of the ureter and the lower pole of the kidney can rarely be tilted so much laterally, that the ureter can be negotiated with a straight instrument. For percutaneous access to the ureter, the nephrostomy should therefore be placed higher, in a middle or even occasionally an upper pole calyx (see Fig. 5.14). This is difficult with high-lying kidneys and may occasionally be the rare indication for an intercostal puncture. Young et al (1985) observed pleural effusion in 8, a hydrothorax in 1 and basal atelectasis in 2 of 24 patients subjected to 12th rib supracostal puncture, so that pleural lesions and even more lung injuries pose serious threats. The excursions of the diaphragm are therefore first assessed by sonography and fluoroscopy during forced inspiration and expiration. Usually the pleural reflection follows the upper border of the 12th rib, and the lower limits of the lung are one-finger breadth higher. The patient's feet are then tilted downwards to lower the kidney as much as possible. With deep expiration the kidney is likewise lowered, but this may result in a kinked nephrostomy channel. Puncture is performed in the posterior axillary line in the middle of the 12th intercostal space. If the needle passes too close to the 11th rib there is a chance of injury to the 11th neurovascular bundle; if it passes too close to the 12th rib the nephrostomy tube tends to kink over the rib and inspiration may be very painful. Punctures above the 11th rib should be avoided.

Although the middle calyces of only 40% of all right kidneys and 30% of all left kidneys are below the 12th rib (Wickham & Miller 1983), they can usually be reached with a subcostal approach by angulating the needle under the 12th rib (see Fig. 5.38). The desired calyx is well-dilated with contrast dye injected via the ureteral catheter and then punctured directly. The soft J-guidewire is threaded through the needle into the collecting system and preferably down the ureter. A 5 F angiography catheter is advanced over the guidewire. The tract is dilated with fascial dilators to 12 F, as described, but the dilators are only advanced into the calyx. They are then exchanged for metal telescope dilators. The kidney can be tilted slightly with the latter, so that the nephroscope sheath can be slid into the collecting system and renal pelvis without a problem.

Antegrade manipulation with the nephroscope

Calculi impacted in the ureteropelvic junction are usually well-visible with the standard nephroscope, and can therefore be managed with the same techniques as renal calculi. With a very dilated ureter even high ureteral stones may be reached with the nephroscope, provided the kidney can be tilted or the nephrostomy be placed through a middle calyx to parallel the course of the ureter with the nephrostomy tract (see Fig. 5.14). If forceps extraction is attempted, only the spring-type two-prong graspers should be used, as their jaws open almost parallel and can be slipped over the stone without tearing the ureter. With three-prong graspers, at least one of the prongs is usually out of sight and may cause ureteral injury.

Stones causing severe dilatation are usually so impacted that they cannot be extracted and ultrasonic lithotripsy has to be utilized. This can be done safely and very efficiently, but it is imperative that a balloon catheter be inflated below the ureteral stone. Otherwise it will gradually be pushed farther down the ureter as it is reduced in size, so that it may disappear out of sight. When utilizing the standard nephroscope within the ureter, irrigation flow rates are almost invariably reduced, as the irrigation port openings on the outside of the tip of the nephroscope sheath are covered. Unless the irrigation system is worked in the reverse direction (see Fig. 5.35) the sonotrode may heat up with continuous use. It should therefore be activated only intermittently, in bursts of 30 seconds, with about the same time between activation to cool off.

In general even tortuous ureters are too narrow to admit the 24 F nephroscope. Forced attempts should be avoided because of the high chance of tearing the ureter at the ureteropelvic junction. By inserting the flexible nephroscope through the standard nephroscope sheath and advancing it down the ureter, the calculus may be visualized and basketed or disintegrated with electrohydraulic lithotripsy. Although feasible, we have found this approach technically difficult and have given it up in favour of retrograde flushing techniques or antegrade ureteroscopy.

Ureteral manipulation under fluoroscopic control

Before thinner endoscopes became available, antegrade ureteral manipulation in slender ureters had to be performed under fluoroscopic control. The main instrument used for this purpose was the stone basket; stone loops are usually insufficient for extraction and triradiate graspers are too dangerous when manipulated without seeing their prongs.

Antegrade basketing faces three major problems:

1. A high risk of perforation with the tip of the basket along the medial aspect of the calculus, especially just below the ureteropelvic junction or at the level of the calculus. Even baskets with soft filiform tips have considerable perforating potential when pushed against the ureteral wall at a blunt angle. The risk is even higher within an oedematous stone bed and a friable ureteral wall, when the basket is deflected tangentially from the calculus in a forced attempt to bypass the stone.

2. The basket does not engage the calculus. Stone baskets were constructed to be worked in the other direction, i.e. from the non-dilated ureter into the dilated ureter. In order to open properly with a symmetrical arrangement of the wires, the ureteral lumen must either be wide or the spring-force of the wires must be sufficient to snap open as the basket is slowly passed by the stone during attempted engagement. Soft or very thin baskets carry a lower risk of perforation, but rarely engage the stone properly due to asymmetric and incomplete opening of the basket.

3. The direction of basket extraction is at a different angle than the course of the ureter. Especially when extraction is performed percutaneously, without a nephroscope sheath, the ureteropelvic junction has to support the major force. This not only carries a high risk of rupture of this segment of the ureter, but also results in a significant loss of force at the basket when pulling the stone over the ureteropelvic junction at an unsatisfactory angle.

To avoid perforation, exclusively for this purpose we use baskets which have a separate sheath and basket (Fig. 5.46). First a 0.035-inch soft guidewire with a J-floppy tip is advanced down the ureter and passed beside the stone. If the stone can be passed at all, it is achieved with this instrument. Occasionally the floppy tip rolls up at the stone. A straight 5 F angiography catheter with an end-hole is then advanced over the guidewire down to the stone, and the guidewire retracted until it just extends some millimetres from the tip of the angiography catheter. Redirected with the angiography catheter, it can usually be passed beside the stone. The guidewire is used as a guide for the basket sheath, which is also passed by the stone. The basket is exchanged for the guidewire and can now be opened distal to the stone. As there is no risk of perforation with this technique, a standard 5 F basket with four wires of good spring quality can be used so that the chances of engaging the stone as the basket is slowly retracted under fluoroscopic control are high. The basket is not closed to avoid trapping the ureteral wall. Antegrade basketing should always be performed through the nephroscope. If the nephrostomy tract is properly placed through a middle calyx, the nephroscope can almost be aligned to the course of the ureter so that an optimal angle of extraction is achieved. If this fails, the nephroscope's tip should be used to take the shearing force of the basket off the ureteropelvic junction.

The rules that apply for basketing stones under fluoroscopic control in the retrograde direction fully apply to this approach. The entire procedure must be monitored fluoroscopically, undue force is to be avoided at all times and the technique has only a reasonable chance of success if the diameter of the calculus is less than the diameter of the dilated proximal ureter. As a primary method for treating calculi in the proximal ureter, the technique is certainly riskier than most techniques under endoscopic control. We have therefore given it up as a primary procedure in favour of the 'retrograde-flush-and-percutaneous-extraction-technique', antegrade ureteroscopy or retrograde ureteroscopy, whatever is more appropriate. Fluoroscopic basketing is only utilized for retrieving smaller fragments which have dropped into the ureter during percutaneous manipulation. They are not impacted and their extraction rarely causes a problem.

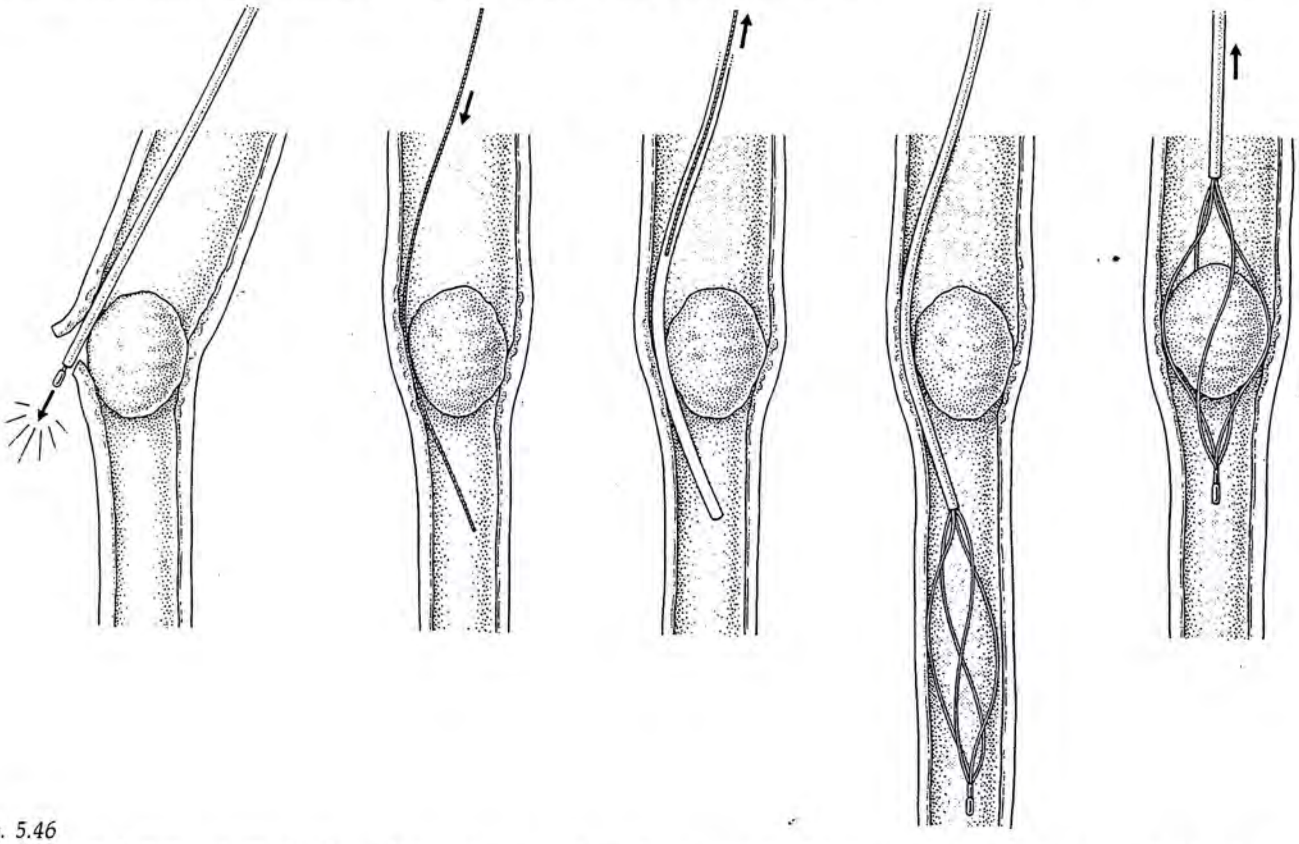


Fig. 5.46

Antegrade stone basketing: rigid baskets have a high tendency to perforate. This is avoided with baskets with detachable sheaths, which can be guided with soft guidewire.

Retrograde flushing and percutaneous extraction

Most ureteral stones are today treated by ESWL, either in situ or after being flushed back into the kidney (see Ch. 3). In the latter situation they are, of course, also amenable to percutaneous removal. Intrarenal endoscopy is certainly less traumatizing than intraureteral endoscopy, at least in the upper ureter. With the technique described in Chapter 16, the stones are almost always flushed into the renal pelvis and only rarely into an upper pole calyx. If the collecting system already was decompressed with a nephrostomy, for example for emergency drainage of an infected and obstructed system, the calculus will invariably rest at the tip of the tube. It can then be extracted percutaneously with minimum morbidity immediately after the ureteral manipulation.

Antegrade ureteroscopy

If the nephrostomy tract can be aligned with the course of the ureter, a rigid rod-lens instrument can be advanced down the ureter. Nephroscopes are usually too large for this purpose, but even with minimal dilatation an 11.5 F ureteroscope can be passed down the ureter without a problem. We use the ureteroscope through the sheath of the 24.5 F nephroscope. The sheath is sealed with a bayonet-lock rubber-shoed cap, so that the ureteroscope can be moved freely within the nephroscope (Fig. 5.47).

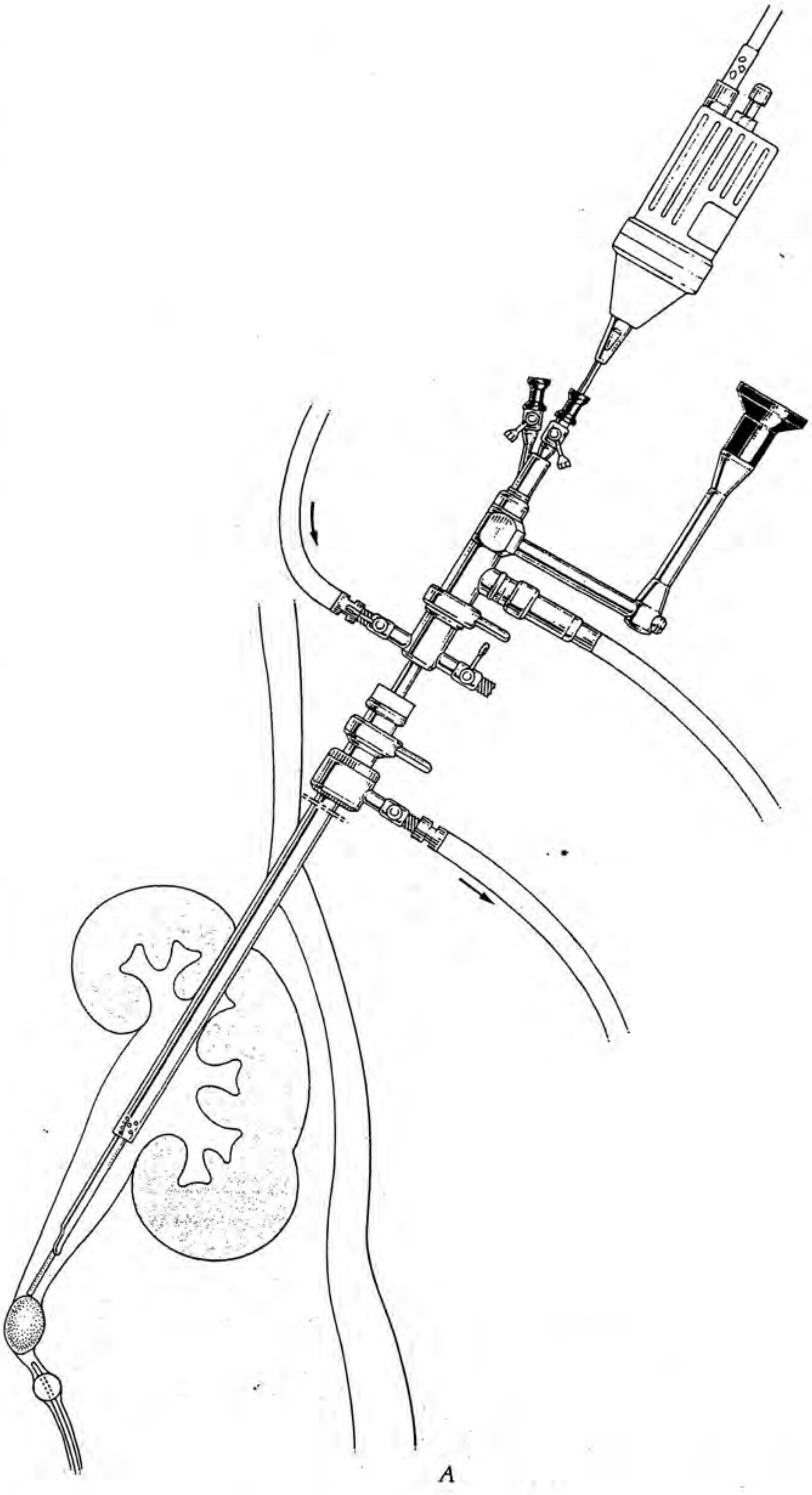


Fig. 5.47

(*A* and *B*) Antegrade percutaneous ureteroscopy and ultrasonic lithotripsy. The inflow port of the ureteroscope is used for adequate cooling of the probe, and the port on the nephroscope sheath for outflow. The left hand of the surgeon stabilizes the instruments and controls the inflow tap. The technique is considerably facilitated by the use of short ureteroscopes (see Fig. 6.10).

The port opening on the nephroscope sheath is used as an outflow channel and one of the ports on the ureteroscope as an inflow channel. Usually the ureteropelvic junction was already identified by nephroscopy and the ureteroscope is inserted with the nephroscope sheath already pointing into the direction of the ureteropelvic junction. The ureter is then simply followed with the ureteroscope under vision until the calculus comes into view.

Smaller stones are basketed. Under sight it is usually no problem to bypass the stone with the basket and engage it. For extraction, the tip of the ureteroscope is brought as close to the calculus as possible and the basket is carefully closed under vision. Basket, stone and ureteroscope are then slowly extracted under vision. It is important to hold the nephroscope sheath firmly during this phase to prevent it from slipping out of the nephrostomy tract; the safety guidewire is imperative for the procedure. Larger stones require ultrasonic disintegration, again with careful monitoring of irrigation and short bursts of ultrasonic disintegration to avoid heat damage. The stone can be disintegrated completely to sand, or just be broken up to larger fragments, which are then extracted one by one with small triradiate graspers or a basket. Alternatively, electrohydraulic disintegration can be utilized for this purpose, especially in wide ureters. To avoid spilling fragments down the ureter, a balloon must be inflated distal to the stone.

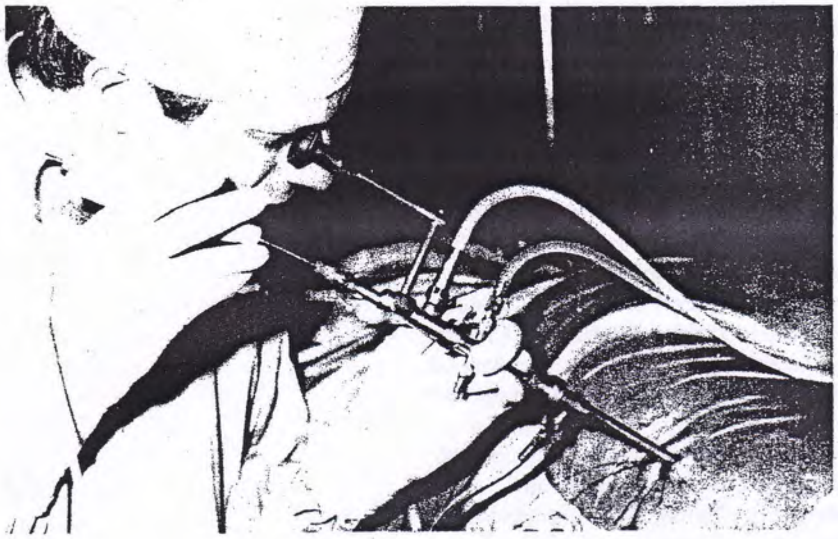


Fig. 5.47(B)

In general, the nephrostomy tract cannot be completely aligned with the direction of the ureter, but an angle of at least 30° can well be overcome by simply tilting the lower pole of the kidney outwards. This usually results in some medial displacement of the ureter, but unless the ureter is fixed in scar tissue from previous surgery the ureteroscope can usually be advanced down to at least the level of the lower pole. The majority of large ureteral calculi are impacted in this region, and therefore are well amenable to this technique. Otherwise they are approached with the flexible nephroscope using an identical technique (Fig. 5.48). As the ureter is usually dilated above the stone, even flexible endoscopes with diameters of up to 18 F can be used. This permits the use of very effective electrodes for electrohydraulic disintegration and facilitates orientation.

After more extensive intraureteral manipulation, or with intraureteral oedema, it is advisable routinely to insert a double-pigtail ureteral stent. It is introduced in the antegrade direction at the end of the procedure through the nephroscope. The correct position of its bladder end is controlled fluoroscopically, and of its renal end endoscopically. In case it was advanced too far, it is simply retracted with alligator forceps, until its proximal end lies in a lower or an upper pole calyx. With the ureter stented, the nephrostomy tube can usually be removed after 12 hours. If the ureter is not stented, the nephrostomy tract may take rather long to dry up. The stent is removed by cystoscopy on an outpatient basis 3–4 days later.

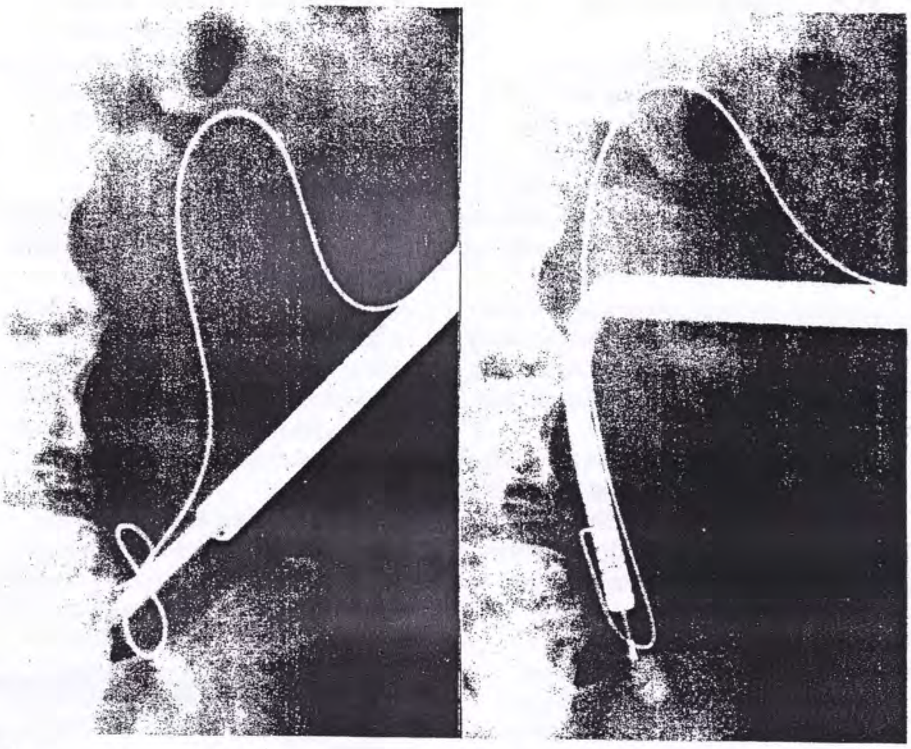


Fig. 5.48

Antegrade ureterscopy: stones further down the ureter (*A*) cannot be reached with the rigid ureterscope, but are amenable to the flexible nephroscope and electrohydraulic (or laser) lithotripsy (*B*) (same patient as in Fig. 9.18).

POSTOPERATIVE CARE

After percutaneous surgery, we routinely drain the kidney with a thin nephrostomy tube, even after the simplest case. The tube is simply inserted through the nephroscope sheath, and advanced into the collecting system as far as possible, preferably into an upper-pole calyx. If this is not possible, the nephroscope is removed and the tube is inserted over the safety guidewire, which is reinforced with an angiography catheter for this purpose.

Most authors recommend a tube larger than 24 F to tamponade the tract and to reduce venous bleeding. Standard Foley balloon catheters with slight traction applied to them have likewise been utilized, and recently the Kaye tamponade catheter resembling a modified angioplasty catheter has become available for this purpose. Provided the nephrostomy tract was dilated bluntly, haemorrhage is almost always of venous origin and will stop spontaneously. In our experience, large-calibre tubes left in the tract for longer postoperative periods only tend to provoke fresh bleeding and to prevent collapsing of the tract so that morbidity is rather increased. We therefore routinely insert only a 14 F tube, which is usually left in place for only 24 hours unless a residual stone or extravasation require further manipulations or longer drainage. In case of significant venous haemorrhage, which usually corresponds with the opacification of major renal veins on the final nephrostogram, the tube is simply clamped for 30–40 minutes until the tract tamponades itself. Diuresis is forced by administering 12.5 g mannitol i.v. within 5 minutes and giving ample intravenous fluid.

The requirements which a nephrostomy tube suitable for percutaneous stone manipulation has to meet exceeds those of an instrument designed for simple drainage purposes. Its lumen must open at the blunt-tip end and it should be large enough, not only to permit the drainage of bloody urine and even clots, but also the passage of two guidewires and even a 6 F angiography catheter. They should be rigid enough to be advanced down the tract over a guidewire with little tendency to kink, buckle or collapse. These prerequisites rule out pigtail and angiography catheters and basically limit the choice to straight tubes. A variety of purpose-built tools of this type are today commercially available. Some feature radiopaque markings to facilitate fluoroscopic control.

Spontaneous tube displacement is a major problem, in particular if staged percutaneous procedures are planned. A variety of nephrostomy tubes including Malecot or balloon-tipped catheters, tubes with a balloon for fixation in the perirenal fat and tubes with retention-discs to secure them to the skin were designed to prevent this. In our experience none is completely satisfactory. The Malecot tips tend to provoke haemorrhage and do not reliably eliminate dislocation. Balloon-tipped catheters drain poorly and may even obstruct upper-pole calyces in kidneys with an intrarenal collecting system. We therefore routinely use straight, blunt-tipped polyurethane tubes with an end- and one-side hole and a calibre of at least 12 F, which are secured to the skin with a suture and medical adhesive tape. They are available from sizes 10 F to 24 F, have radiopaque markers and detachable funnel-shaped ends so that they can be inserted through the nephroscope sheath (Fig. 5.49).

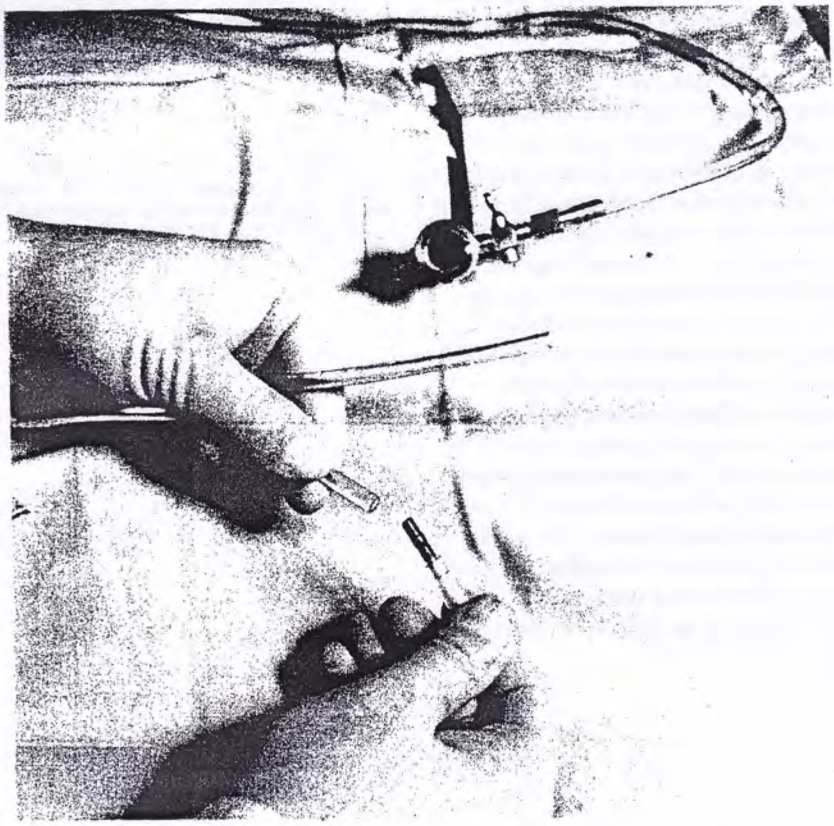


Fig. 5.49

Straight open-ended nephrostomy tubes with radiopaque tips and a detachable funnel are inserted through the nephroscope sheath for postoperative drainage.

Even when properly secured to the skin, tubes are dislocated rather easily from the kidney because of respiratory movement, in particular in obese patients with mobile kidneys. This is best prevented by advancing them as far into the collecting system as possible, at least 5–6 cm. Tubes advanced down the ureter are safest, but large-calibre catheters obstruct urinary drainage and promote extravasation. In our standard approach, the tube therefore enters a lower-pole calyx and passes through the pelvis into an upper-pole calyx in the immediate proximity of the calculus to be removed. If this position is difficult to maintain, the nephrostomy tube may be secured with a stiffer angiography or pigtail catheter, which is inserted through the thicker tube and holds it in position.

Regardless of the type of anaesthesia used, the patients are usually ambulatory on the evening of the day of the operation. One to two litres of fluid are administered intravenously in the immediate postoperative period, but thereafter the patient is allowed to drink freely. Food is withheld for a maximum of 24 hours. With a sterile urinary tract, antimicrobial agents of the trimethroprim type are administered prophylactically during the period of nephrostomy drainage. Identified urinary infection is treated specifically. Poorly-draining nephrostomy tubes are flushed with saline to dislodge any obstructing clots. If they do not drain in spite of not being obstructed, with flank pain or fever, a nephrostogram is obtained and the kidney is screened by sonography. Occasionally the tube is dislocated but still within the collecting system. It is then repositioned over a guidewire, under fluoroscopic control. If it is found to be dislocated outside the kidney and the kidney is not obstructed and sonography shows no extrarenal fluid collections, the tube is removed. If the kidney appears obstructed and fever persists, a double-pigtail ureteral stent is inserted. We routinely pass a suture through the bladder-end of the stent, which is left dangling out through the urethra, so that cystocopy is not necessary to remove the stent. The nephrostomy tract is only re-established with significant obstruction and persisting symptoms, significant extravasation, or residual stones. Extrarenal fluid collections are tapped percutaneously. As they always result from extravasation, the kidney must also be drained properly by a percutaneous nephrostomy tube or an internal ureteric stent.

RESULTS

The success rate of percutaneous stone manipulation depends on patient selection, the experience of the surgeon and the equipment available. Both percutaneous nephrostomy and endoscopic manipulation require considerable training and all statistics reflect a learning curve. We experienced a failure rate of 15% in our first 16 patients subjected to ultrasonic lithotripsy (Marberger et al 1982) and it dropped to 6% in the first 1500 patients, in spite of including practically all types of stones (Table 5.1). Once the learning problems are overcome, and provided a full armamentarium of equipment including ureteroscopes, miniature and flexible nephroscopes is available, the results mainly depend on the type and the localization of the calculus being treated. With pelvic calculi in a rather dilated collecting system, the success rate approaches 100%, whereas with small calyceal stones in an anterior middle calyx with a delicate collecting system and a very mobile kidney, failures are quite frequent. Complicated stones may require multiple interventions, usually to remove fragments from calyces or the ureter, but in general the overall success rates in large series today exceeds 95% (Alken et al 1983, Marberger et al 1985, Segura 1985).

The majority of renal and ureteral calculi can be managed endoscopically. In Vienna, ESWL did not become freely available before 1985, so that in 1984 percutaneous surgery was the only alternative to open surgery. Eighty-five per cent of the patients were managed endoscopically. At this time ureteroscopes permitting ultrasonic disintegration under vision were not available, so that a substantial number of patients were still subjected to open ureterolithotomy; today all of these patients would be managed endoscopically. If this group and the patients subjected to nephrectomy because of a completely destroyed, usually pyonephrotic kidney, are excluded, the percentage of patients treated endoscopically rises to 92%.

Some of the patients treated by open surgery require reconstructive procedures to improve urinary drainage. A limited number of patients with ureteropelvic obstruction can be managed with percutaneous pyelolysis (Wickham & Miller 1983, Korth 1984, Badlani et al 1986, Whitfield 1987), although late results of this procedure are not yet available. There remains a small group of patients who could have been treated percutaneously, but in whom the percutaneous approach was considered to be more complicated and disadvantageous for the patient than open surgery. This group comprises patients with very branched staghorn stones, or multiple peripheral calculi in different calyces. Some authors manage stones of this type percutaneously too, but in our experience complete stone clearance is difficult to achieve in spite of multiple nephrostomies and interventions (see Table 5.1). Ultimately it adds up to many hours of endoscopic manipulations and long hospitalization. These stones are today better treated by combining percutaneous nephrolithotripsy for 'debulking' and ESWL for disintegration of peripheral calculous remnants.

Table 5.1 Complications of percutaneous stone manipulation in 1500 renoureteral units (Rudolfstiftung, Vienna); complications requiring open surgery in parenthesis

	Pelvic calculi[1] $n = 879$ r.u.	Calyceal calculi[1] $n = 243$ r.u.	Branched calculi[1] $n = 186$ r.u.	Ureteral calculi[1,3] $n = 192$ r.u.
Mortality[2]	1	—	—	—
Nephrectomy	—	—	—	—
Insufficient tract, or stone not reached/failure	16 (10)	7 (2)	1 (1)	8 (8)
Art. haemorrhage requiring intervention[4]	7 (3)	2	3	3
Perirenal haematoma	2	—	1	1
Trapped stone basket	—	—	—	1
Residual stones[5]	30 (2)	18	45 (2)	1
Myocardial infarction	1	—	1	—
Pulmonary embolism	4	—	1	—
Exacerbation of renal tuberculosis	—	1	—	—

[1] With multiple stones the most difficult calculus was used for group assignment.

[2] Arterial haemorrhage, solitary kidney in 73-year-old patient, surgical exploration twice, finally angioinfarction; death from clotting disorder and pulmonary distress.

[3] Antegrade ureteroscopy in 147 r.u. units.

[4] Superselective angioinfarction in 12 r.u. units.

[5] Visible on plain film at discharge.

With better availability of ESWL the population of patients subjected to endourological procedures has changed dramatically (Table 5.2). In contrast to 'pre-ESWL' times, the bulk of patients managed endoscopically today have ureteral stones, stones larger than 2 cm in diameter, or urinary outflow obstruction. The choice of treatment for the individual patient is still under debate and the reader is referred to Chapter 9 in this context.

COMPLICATIONS

Once the initial learning problems are overcome, the postoperative morbidity of percutaneous procedures is minimal. There are no limitations when using the technique in solitary kidneys, poorly functioning kidneys, or kidneys which have been subjected to previous surgery. Provided the paediatric nephroscope or, in infants, the minimal nephroscope is used, there is no age limitation for percutaneous surgery; we dilated nephrostomy tracts to 14 F in babies for various non-calculus conditions and did not observe significant complications from haemorrhage, or loss of renal function. Gross obesity complicates the procedure, yet we have so far not seen a patient for whom the standard instruments were too short.

Postoperative hospitalization depends on the type of stone, the condition of the patient and the local medicosocial system. Using a one-stage approach, it averaged 2.4 days in 100 consecutive patients treated at this institution if the stone was extracted, and 3.3 days in 100 consecutive patients subjected to ultrasonic lithotripsy (Table 5.3). Similar results were achieved with the percutaneous management of ureteral calculi, provided the ureter was stented postoperatively. With good outpatient supervision, hospitalization can probably be reduced further and simple stones could probably be removed on an outpatient basis. Almost all patients are pain-free and asymptomatic at the time of hospital discharge and fit for office or light housework.

Table 5.2 Treatment selected to remove upper tract urinary stones at the Rudolfstiftung Hospital, Vienna (excluding ablative procedures); percutaneous procedures were started in 1980, ureteroscopy in 1981 and an ESW-lithotriptor was installed in 1986

	1980	1984	1988
Open surgery	77%	13%	< 1%
Zeiss loop	19%	10%	< 1%
Endoscopy (including treatment combined with ESWL)	4%	77%	21%
ESWL	—	—	78%
No. of patients treated per year	151	658	1409

Table 5.3 Results of one-stage percutaneous nephrolithotripsy of pelvic calculi in 100 consecutive patients treated by percutaneous extraction (stone diameter < 11 mm), and 100 consecutive patients treated by ultrasonic lithotripsy (stone diameter > 11 mm), but otherwise identical techniques, (3/1985–8/1985 Rudolfstiftung, Vienna); today most of these stones would be treated by ESWL, which was not available then (see Table 5.2)

	Percutaneous extraction	Ultrasonic disintegration
Failure to remove stone	—	1%
Haemorrhage requiring intervention	1%	—
Blood transfusion	1%	3%
No. sessions/kidney	1.05	1.1
No. nephrostomies/kidney	1.07	1.15
Residual stones	2%	8%
Mean p.o. hospitalization (d)	2.4	3.3
No. patients	100	100

If the procedure is staged and, in particular, if multiple interventions become necessary to remove a staghorn stone, morbidity, of course, increases (Table 5.4). It is this patient group that profits most from combining percutaneous procedures and extracorporeal shock wave lithotripsy, as procedural and fluoroscopy times are significantly reduced (see Chs 7 and 9).

Table 5.4 Results of percutaneous lithotripsy of staghorn stones in 120 kidneys of 108 patients (Rudolfstiftung, Vienna 1980–1986)

No. nephrostomies/kidney	2.1
No. sessions/kidney	1.6
Average hospitalization	10.4 days
Average anaesthesia time	138 min
Patients requiring blood transfusion	8%
Patients with fever > 38.5°C	11%
Cardiovascular complications	3%
Nephrectomy	—
Mortality	—

Renal damage

The impact of percutaneous nephrolithotomy on renal function is in general insignificant. The risk of damaging the kidney certainly increases with the diameter of the tract, but blunt dilatation seems to prevent severe functional and morphological deterioration. A 24 F nephrostomy left no significant impact on the morphology and overall function of canine kidneys (Webb & Fitzpatrick 1985a) and similar results were noticed after 34 F nephrostomies in porcine kidneys, which are larger than canine kidneys and approximately the size of human kidneys (Clayman et al 1987).

Kellett et al (1983) observed a 10% decrease in the DMSA scan after percutaneous nephrolithotripsy in 1 of 14 human kidneys; it had been subjected to three subsequent punctures. A late follow-up study was performed in 82 of our first patients treated percutaneously. At computerized tomography, 79% of the kidneys appeared absolutely normal after lithotripsy, and this figure rose to 85% if kidneys which had been subjected to previous open surgery were excluded. Only 1 of 62 kidneys showed a cortical scar 1.2 by 1.5 cm in diameter as a sign of cortical infarction, but the overall function of the kidney was not impaired. The former nephrostomy tract could only be identified in 46% of the patients, usually by a delicate scar through the abdominal wall; only 1 patient showed more significant alterations of the psoas muscle from resorption of a large haematoma. Split ^{131}I-Hippuran clearance studies obtained preoperatively and one year after nephrolithotripsy were unchanged (Marberger et al 1985a). Even multiple nephrostomies in the same kidney are well tolerated, provided the tracts are dilated bluntly and postoperative obstruction is avoided. A follow-up study of 59 kidneys treated in this manner showed only 5% of the kidneys to have a cortical scar, visible at computerized tomography at one of the former puncture sites (Stackl et al 1987); in essence, the results were practically identical to the follow-up series after one nephrostomy.

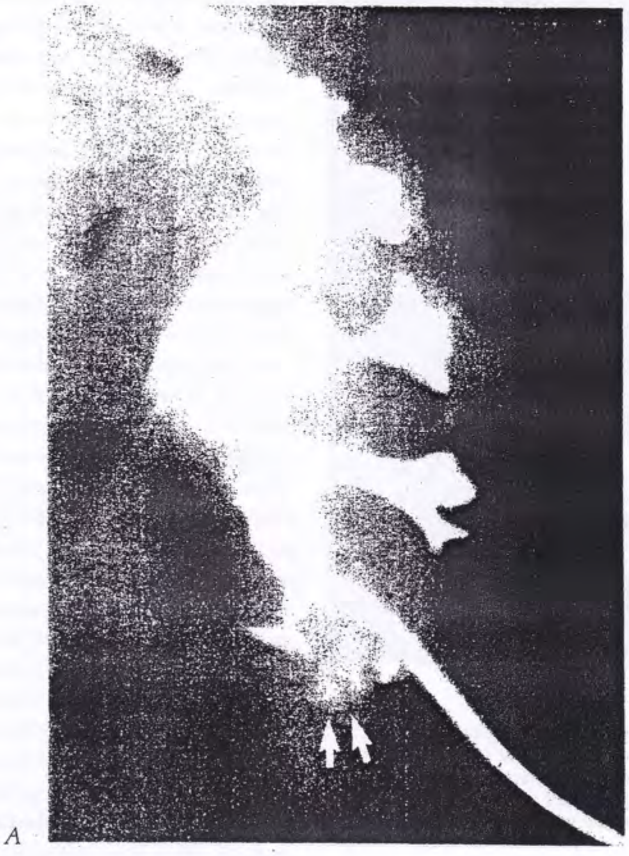
Incorrect nephrostomy tract

The success of percutaneous stone manipulation relies heavily on the correct placement of the nephrostomy tract, which should permit direct access to all calculi with rigid endoscopes. This is mainly a problem of experience. Once the technique of percutaneous nephrostomy is established, i.e. approximately 100 patients have been successfully treated percutaneously, access to simpler renal stones rarely causes problems. Difficulties may then arise from either the dislocation of stones during intrarenal manipulation, so that they cannot be reached from the original tract, or the misplacement of the nephrostomy tract into an adjacent calyx, which does not permit access to the stone-bearing calyx.

In the former situation we have found attempts at flushing the stone back into more accessible parts of the system with catheters, or retrieving it with the flexible nephroscope, frequently tedious and unsuccessful, and prefer to place a second nephrostomy tract into the appropriate calyx (see Fig. 5.38). Occasionally the stone can then be manipulated or flushed back into the pelvis with the miniature nephroscope, or else it is removed directly from the calyx.

The latter situation is more difficult to manage. In the typical case a small calyceal stone is located in an anterior calyx, but the tract enters the kidney through a posterior calyx; the ridge between the two infundibula is impossible to negotiate, even with a flexible nephroscope. In spite of the obvious proximity of the two calyces we never attempt to divide the tissue in between (Wickham & Miller 1983); we consider this to carry too high a risk of haemorrhage. It may already be difficult to determine whether the nephrostomy tube is in the correct calyx or not. Small stones embedded in the calyceal cusp can only be seen when the nephroscope is retracted almost to the level of the parenchyma. At this point there is usually some haemorrhage, so that vision is obscured. We then find it helpful to reduce irrigation outflow briefly to overdistend the collecting system. Magnification fluoroscopy and plain-films are extremely helpful, but contrast dye should not be injected in order not to camouflage the calculus. Once the incorrect tract position is established, a guidewire is left in this tract and the nephroscope removed.

Using the same tract through the skin and abdominal wall, the stone-bearing calyx is now punctured directly onto the stone (Fig. 5.50). By using the thin inner-needle of the three-part coaxial system, the stone can frequently be tipped directly and occasionally it can be pushed into a part of the collecting system common to both calyces. Otherwise a 0.035 inch J-guidewire is inserted through the needle and into the pelvis, and the tract is dilated to accept either the paediatric nephroscope or the standard nephroscope. The two tracts should not be instrumented with large-calibre instruments at the same time, to avoid damage of the tissue between them. Nevertheless, the parenchyma frequently splits between the two tracts, but as this is performed bluntly, haemorrhage is rarely a problem. Overall, problems with positioning the nephrostomy tract rapidly disappear once the learning phase is mastered. In our overall series the rate of failures for this reason is already below 2% and it is decreasing further in spite of more difficult stones being managed.



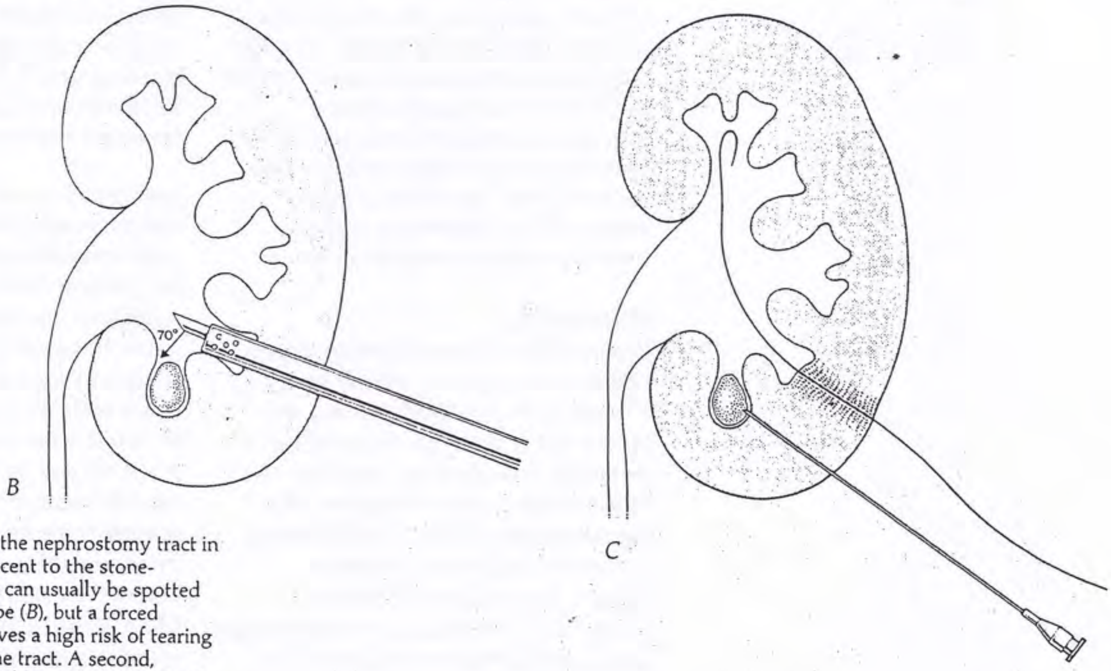


Fig. 5.50

(*A*) Incorrect position of the nephrostomy tract in a calyx immediately adjacent to the stone-bearing calyx. The stone can usually be spotted with a 70° insert telescope (*B*), but a forced attempt to reach it involves a high risk of tearing the parenychma along the tract. A second, correct puncture is preferable, with the first tract secured with a guidewire (*C*).

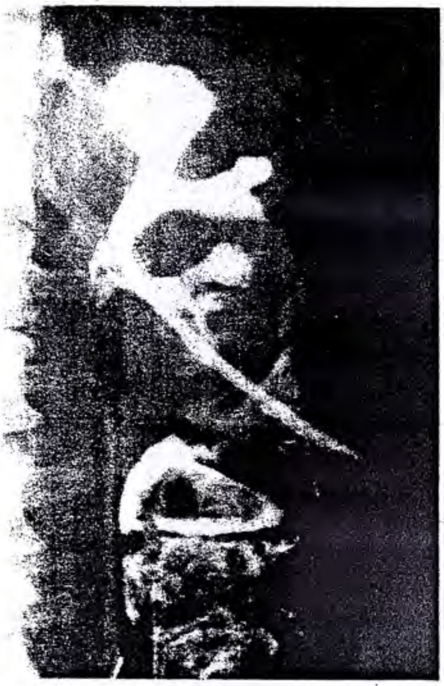


Fig. 5.51

'Transcolonic' percutaneous nephrolithotripsy: the bowel perforation was noticed only on the final nephrostomogram after stone removal; recovery was uneventful under antibiotic coverage and retrieval of the tube three days later.

Inadvertent injury to the pleural cavity, the colon, the liver, the spleen and the gallbladder has been reported (Wickham & Miller 1983, Clayman et al 1984, Carson 1985); injuries to the duodenum, the pancreas and the larger abdominal vessels theoretically appear possible. The pleura is almost exclusively opened with punctures above the 12th rib and this frequently results in a pneumohydrothorax, requiring drainage by a chest tube. With a supracostal puncture a nephrostomy sheath should routinely be used to reduce the risk of a hydrothorax from leakage of irrigation fluid alongside the tract (Clayman 1984, Young et al 1985). A chest X-ray must always be obtained at the end of the procedure. Injury of the colon may be noticed at the time of puncture by the escape of gas from the needle; after redrawing the needle the lesion seals spontaneously without further problems. Occasionally the colon is inadvertently intubated with a nephrostomy tube and this is only noticed at an attempted nephrostogram (Fig. 5.51); antibiotic cover, a double-pigtail ureteral stent or a nephrostomy placed correctly at another site, and gradual withdrawal of the tube seems to be the only therapeutic measure needed (Alken et al 1983). Postoperative bowel distension is observed frequently after percutaneous lithotripsy and this may be an indirect sign of minor bowel lesions. In our experience, it always resolves with conventional measures.

Haemorrhage

Provided the contraindications of percutaneous manipulation, mainly renovascular malformations, clotting disorders and severe hypertension, are respected, haemorrhage requiring an intervention occurs in less than 1% of the procedures (Table 5.3). If bleeding obscures vision during intrarenal surgery it is imperative that the procedure is stopped to prevent damage from uncontrolled manipulation. It is usually of venous origin and rapidly stops spontaneously. Some authors recommend large-calibre nephrostomy tubes (Alken et al 1983) or balloon catheters (Clayman et al 1983b) to tamponade the bleeding tract, but in our experience freshly dilated tracts collapse rapidly and a 14–16 F tube usually suffices. A nephrostogram is routinely obtained, and this may occasionally show opacification of a large vein (Fig. 5.52) and even the vena cava. In this situation the tip of the nephrostomy tube must be positioned well away from the venous lesion, as it may otherwise drain the vein directly and prevent its collapse. If haemorrhage continues in spite of forced diuresis, the tube is simply clamped for some minutes for self-tamponade of the tract.

With continuing haemorrhage, an arterial lesion must be suspected and an arteriogram has to be obtained. Arterial lesions are best managed by superselective embolization with autologous clot or Gianturco coils (Fig. 5.53). Provided the patient's circulatory situation is stable, open exploration should be avoided at all costs, as intraoperative inspection of the kidney rarely permits identification of the bleeding vessel. The procedure is often insufficient and may result in an unnecessary nephrectomy.

Amino-caproic-acid should not be administered routinely, as it promotes clot formation and retention, but does not prevent haemorrhage from significant vascular lesions. If bleeding is noted alongside the nephrostomy tube, a second suture at the site of the stab injury seals the wound around the tube, so that it is tamponaded. In this situation, and basically always after significant haemorrhage, the kidney and retroperitoneum should be controlled by sonography and a nephrostogram before the nephrostomy is removed. Clots in the collecting system dissolve spontaneously within 24 hours.

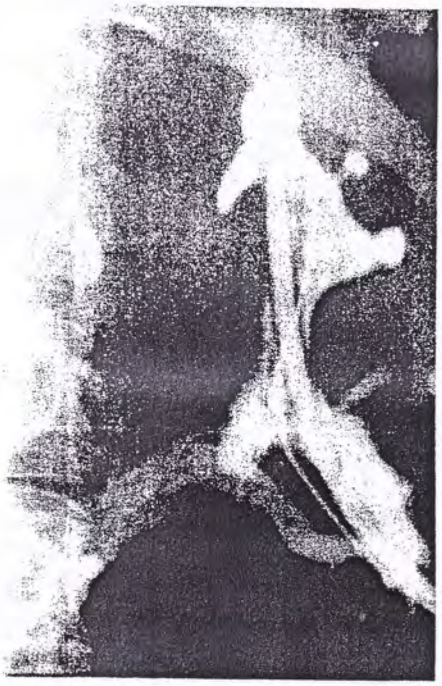


Fig. 5.52

Laceration of a major branch of the renal vein: haemorrhage ceased within 20 minutes after the nephrostomy was clamped for self-tamponage.

Occasionally perirenal haematomas are detected, which should be followed sonographically until they dissolve. This usually occurs within 1–2 weeks, but 2 of our patients had to be readmitted after 2 and 4 weeks respectively because of large perirenal haematomas. Both were managed percutaneously by placing a 14 F tube directly into the haematoma and draining the kidney with a nephrostomy.

Patterson et al (1984) reported a 0.6% late haemorrhage rate from pseudoaneurysms or arteriovenous malformations after percutaneous nephrolithotomy, and we also observed one such patient. This complication certainly must be considered the most important potential hazard of the procedure. It seems to be directly related to the trauma of dilatation and manipulation and is best prevented by a precise puncture technique, blunt-tract dilatation and gentle manipulation, which avoids tearing or cutting of renal tissue. If late haemorrhage occurs, renal arteriography and superselective embolization of any arterial lesion are again the treatment of choice.

Theoretically, perirenal haematomas and subsequent perirenal scarring or focal cortical malperfusion from an arterial lesion or superselective embolization could cause hypertension. At the present time, no data has been presented to substantiate this. In our late follow-up study on 82 patients we found no evidence of an increased rate of hypertension after percutaneous nephrolithotomy (Marberger et al 1985a).

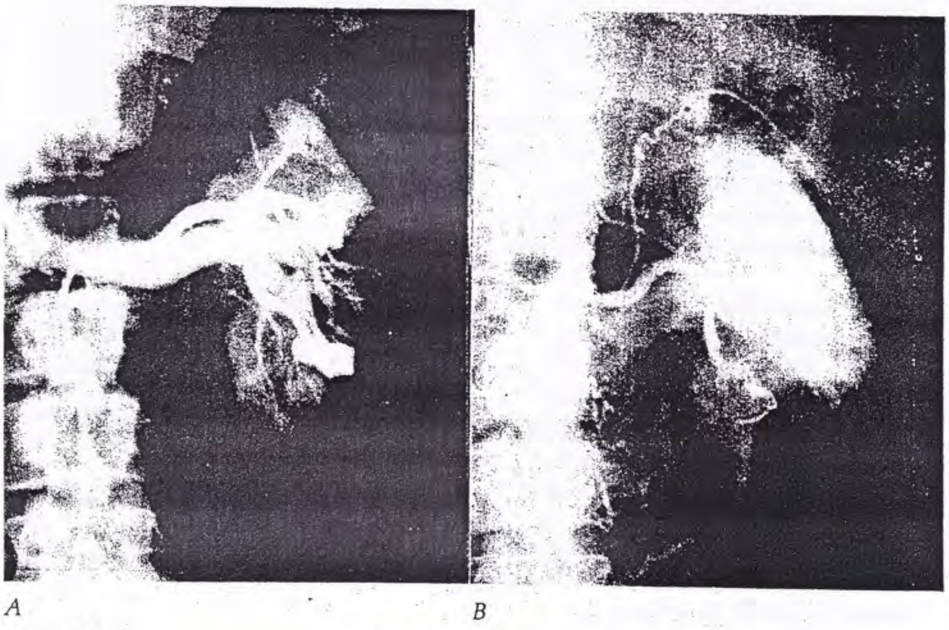


Fig. 5.53

(*A*) Laceration of the posterior segmental archery, causing severe arterial haemorrhage; (*B*) the posterior segmental archery was embolized peripherally with Gianturco coils and haemorrhage stopped immediately; function of this kidney was only minimally reduced after 14 days on a DMSA scan.

Perforation of the collecting system

Isolated lesions of the collecting system occur rather frequently, and provided overdistension of the system and mechanical manipulation around the lesion are avoided and the kidney is drained postoperatively the procedure can be terminated as usual. With a significant perforation intrarenal manipulation should be interrupted, although even large amounts of saline are mobilized without a problem from the retroperitoneum. If electrolyte-free solutions as used for transurethral surgery are employed as irrigant, a 'TUR-syndrome' may develop. Characterized by severe hyponatraemia, hypoosmolarity and water intoxication, it has been one of the rare reasons for a fatal complication of percutaneous renal surgery (Schultz et al 1983); saline must be used exclusively. Frequently massive extravasation is noticed unexpectedly at the final nephrostogram (Fig. 5.54). The leaks seal within hours, provided the kidney is drained with a properly positioned nephrostomy tube. Overall, complications from extravasation have not caused problems in our experience and, therefore, we do not bother with the cumbersome monitoring of the inflow and outflow volume of irrigation fluid to detect unnoticed extravasation; routine postoperative nephrostomy drainage and the nephrostogram have proven to be sufficient safety measures.

With an uneventful intraoperative course the nephrostomy is usually removed after 24 hours. Unless the ureter is obstructed the tract closes within 24 hours. Otherwise the ureter is stented with a double-pigtail stent. If extravasation was noted at the end of percutaneous surgery, the nephrostogram is repeated after 24 hours and the tube is only removed if all leaks have closed. With symptoms of perirenal fluid collections, in particular fever and a tender flank, the kidney is screened by sonography at short intervals. Any extrarenal fluid collections are drained percutaneously and do not refill, provided the kidney itself is drained correctly. We have not observed late urinomas.

Infection

In our experience, infection has not caused significant problems. If urinary infection is diagnosed prior to treatment, appropriate antimicrobial therapy is initiated 1–2 days previously. Frequently infection cannot be eradicated and often an acute septic condition from stone obstruction requires immediate intervention. In this situation, the primary therapeutic goal is urinary drainage and this is best achieved by immediate percutaneous nephrostomy. Stone removal is delayed until the urine has cleared up and all signs of septicaemia have disappeared. We have never considered urinary tract infection per se a contraindication to percutaneous stone manipulation. Although infected patients are usually treated with staged procedures, and have a slightly longer postoperative hospitalization and a higher rate of postoperative fever, the overall complication rate is not higher than with non-infected patients. We analysed the clinical course of 1700 patients we treated percutaneously in this respect. In 240 of them the culture was positive preoperatively. As expected, mean preoperative hospitalization was significantly longer (3.5 days versus 1.2 days) and fever > 38.5°C more common (28% versus 16%) in the infected group. Postoperative hospitalization, however, was similar (mean 3.9 days infected versus 3.3 days non-infected), and specific complications, such as perinephritic abscess or pyonephrosis necessitating nephrectomy, were never observed.

During nephrostomy drainage all patients are covered prophylactically with an antimicrobial agent. Occasionally, even a non-infected patient experiences chills, or a sharp rise of temperature in the immediate postoperative period, but this is almost always due to incorrect drainage and responds immediately to repositioning of the tube. With postoperative fever the kidney and perirenal area are screened by sonography at short intervals. Uncontrollable postoperative septicaemia and intra- or extrarenal abscesses were never observed. In the late follow-up study no patients sterile preoperatively were found to be infected, and 72% of the patients infected preoperatively were sterilized after the procedure (Marberger et al 1985a).

Table 5.5 Residual stones after percutaneous lithotripsy of staghorn stones in 120 kidneys, correlated to stone analysis (same patients as in Table 5.4)

	n	All residuals	Stones > 5 mm
Struvite/calcium phosphate	73	34%	16%
Calcium oxalate	34	26%	7%
Uric acid (+mixed)	9	11%	—
Cystin	4	25%	—
	120	30%	12.5%

Residual stones

Every technique of intrarenal stone disintegration has an inherent risk of leaving fragments behind and even with simple stone extraction we have seen parts of the calculus break off and be left behind (see Table 5.1). The rate of residual stones is mainly a result of the perseverance of the surgeon and his surgical technique. The problem can be reduced considerably by a careful step-by-step fragmentation technique, careful monitoring of the continuous flow irrigation system and adept use of the multiple nephrostomy technique and/or the flexible nephroscope. The availability of fluoroscopic control during all phases of intrarenal manipulation is mandatory. The residual rate naturally also depends on the stone being treated; in our experience it varied from 2% for simple pelviceal stone requiring only extraction to 34% for struvite staghorn stones (Table 5.5). Fifty-four per cent of the patients of the latter group were subjected to a second procedure in general anaesthesia to remove fragments. The residual rate could certainly have been reduced further by additional percutaneous manipulation, but usually the residual material was calculous 'dust' of a particle size that could be expected to be passed spontaneously, in particular when compared to the particles produced at ESWL.

In the majority of patients subjected to intrarenal or intraureteral stone disintegration, this was achieved by ultrasonic lithotripsy. Wickham & Miller (1983) reported on 2 patients with early recurrent stones after this technique in a series of 42 patients. They suggested that the fragments observed after ultrasonic lithotripsy may act as nidus for rapid new stone formation. Neither our data, nor the experience of Alken et al (1983) and Segura et al (1983) supports this theory. We recently updated our late follow-up series (Marberger et al 1985a) in this respect, extending it to our first 100 consecutive patients with a mean follow-up of 2.9 years. Of the 13 patients in whom residuals were documented at discharge, 3 patients with larger fragments left behind subsequently required an additional percutaneous procedure because these dropped into the pelvis or ureter. In 4 patients the fragments were passed spontaneously and in the rest they remained unchanged: 5 patients of the latter group had minute residuals < 2 mm only. Computerized tomography showed that these were located within the parenchyma in 1 patient and in the peripelvic fat in another patient.

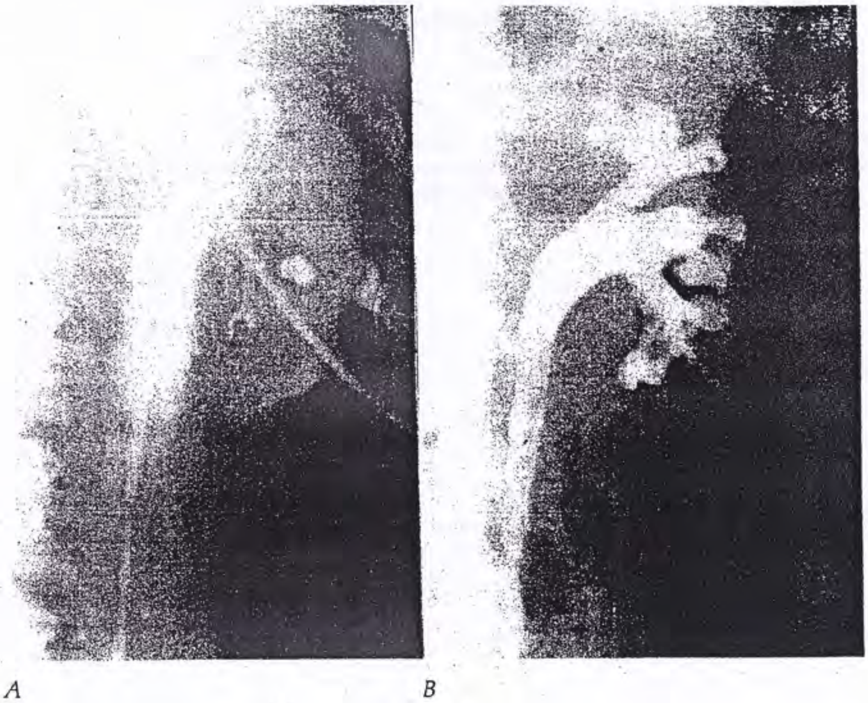


Fig. 5.54

(*A*) Severe extravasation at final nephrostomogram after percutaneous stone manipulation. The nephrostomogram (*B*) 6 hours later shows complete sealing of the leak; the residual clots dissolved spontaneously within 24 hours and further recovery was uneventful.

Failure to correct underlying causes of stone formation almost inevitably results in growth of residual stones. This becomes most obvious in the follow-up of struvite stones, where infection cannot usually be eliminated in the presence of residual calculous material, and at least larger fragments left behind almost always grow (Table 5.6). Complete stone removal should still be attempted today, and more perseverance in particular with the flexible nephroscope would probably have improved the results given in Tables 5.4 and 5.5. With a precise follow-up and early treatment of growing residuals with painless ESWL or percutaneous techniques, the problem can be kept at an acceptable magnitude.

Recurrent stone formation

Although the follow-up period is too short for a definite statement on the impact of percutaneous stone manipulation on the recurrence rate, 3 of the 100 patients developed a true recurrent stone 9–27 months after complete stone removal, as documented by a plain-film after the first procedure. In 24 of the 100 patients, stones had already been removed by open surgery from the same kidney prior to the primary percutaneous procedure. A review of this group revealed that 6 patients had also formed a recurrent stone within 24 months after open surgery (Marberger et al 1985a). At the present time no evidence is available for an increased rate of stone growth after percutaneous surgery.

Table 5.6 Rate of recurrent stones and growth of residuals stones after percutaneous lithotripsy of staghorn stones (Rudolfstiftung, Vienna)

Stone analysis no. kidneys	Struvite/ Ca. phosphate $n = 61$	Ca. oxalate $n = 28$
Recurrent stone formation		
overall	16%	7%
requiring treatment	6%	4%
Growth of residuals		
overall	48%	10%
original residual > 5 mm	80%	—

Follow-up 12–58 months (mean 27 months).

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Chapter 6

Transurethral and transureteral stone manipulation

M Marberger

Introduction

It is logical that the use of natural openings for surgical access to the inside of the body will reduce morbidity. Since the beginning of medical intervention, the urethra has been catheterized to relieve outflow obstruction, dilate strictures and push back obstructing stones, but it was not until Jean Civiale's (1827) ingenious invention of an effective transurethral lithotrite that the urologist started to shed the halo of the barber-lithotomist. Nitze's invention of the cystoscope (1879) added the final cornerstone to the foundations of endourology, which is visual control. An explosion of new technologies, in particular in the last 10 years, opened the entire urinary tract to transurethral manipulation.

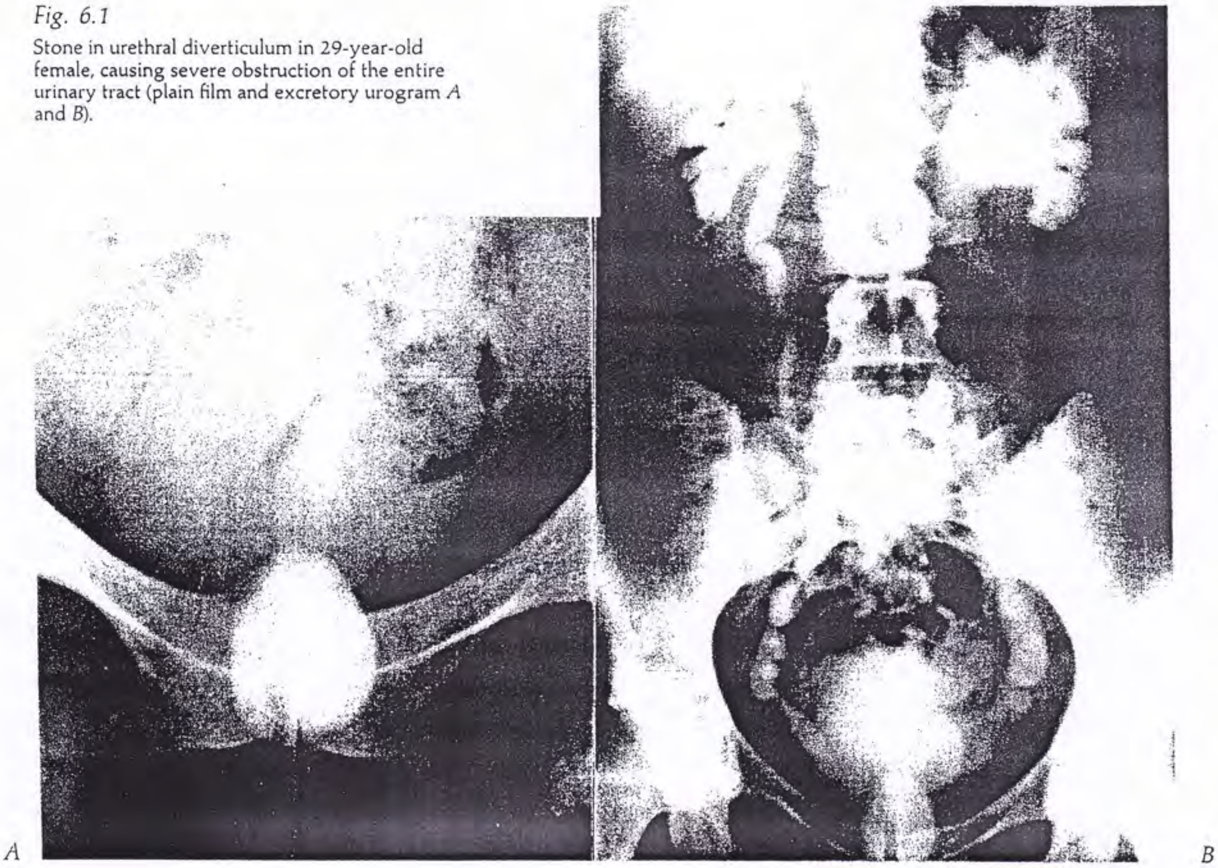
URETHRAL CALCULI

Occasionally, stones being discharged spontaneously become impacted in the urethra. As with a normal urinary tract, the ureter is the most narrow segment of the collecting system, this only occurs when vesical calculi are passed or the urethra is strictured. In the former situation the calculus usually lodges just proximal to the meatus, in the latter proximal to the stricture. Occasionally, smaller calculi collect in the dilated segment of the urethra above a stricture, gradually to grow to considerable size. Very large stones may form in abnormal cavities, such as diverticula, remnants of the Muellerian duct, or cavities after prostatic surgery (Fig. 6.1).

A stone in the meatus can usually be removed with forceps, if necessary under local anaesthesia. Most other stones can be pushed back into the bladder with the panendoscope, to be disintegrated there. In the rare situation that an impacted stone cannot be dislodged, it can be disintegrated in situ using a short ureteroscope and ultrasonic lithotripsy. Stones in large diverticula can usually be treated like vesical stones with electrohydraulic lithotripsy and the panendoscope, whereas stone-bearing Muellerian remnants may only be negotiable with a ureteroscope and ultrasonic or laser lithotripsy. Correction of the underlying pathology is essential to prevent recurrent stone formation and it is usually performed in the same session.

Fig. 6.1

Stone in urethral diverticulum in 29-year-old female, causing severe obstruction of the entire urinary tract (plain film and excretory urogram *A* and *B*).



VESICAL CALCULI

In the western hemisphere, vesical calculi have become a rare clinical entity that is virtually only observed in combination with infravesical obstruction or chronic infection. As a consequence, stone removal is usually combined with correction of outflow obstruction. Except with extremely large benign prostatic hyperplasia and/or large bladder stones, this is almost always performed endoscopically.

In contrast, bladder stones are still endemic in some countries of south-eastern Asia; in Thailand this diagnosis still contributes up to 500 hospital admissions per year per 1 million of the population (Halstead 1977). The condition is diagnosed almost exclusively in boys younger than 3 years, without any evidence of outflow obstruction or urinary infection. The stones are obviously caused by a chronic protein deficiency resulting from a pure rice diet, aggravated by dehydration, heat and recurrent diarrhoea. In girls, the microliths are obviously passed continuously, whereas in boys the anatomical situation promotes stone growth. Just like endemic bladder stones in children in western Europe in the 19th century, the problem will probably be eliminated in the near future with better balanced nutrition (Williams & Eckstein 1968). Endemic stones show no tendency to reform after removal, obviously because the children have outgrown their critical phase of an unbalanced diet. Of course these stones can also be treated with the standard urological techniques, but the delicate urethra of this age group requires sophisticated instruments with an external diameter of < 10 F. As the stones are frequently very hard and large, a simple suprapubic cystolithotomy through a minimal Pfannenstiel incision is frequently the simpler and less invasive approach (Hohenfellner & Marberger 1977).

Mechanical litholapaxy

Blind lithotripsy with the jaws of a powerful lithotrite under tactile guidance only has proven very successful in the hands of experts (Hadley et al 1977, O'Flynn 1980), but the high risk of severe bladder damage in the hands of the beginner has rendered the technique virtually obsolete. The addition of optical systems improved the safety of mechanical lithotrites, but resulted in a loss of strength and efficiency. As most instruments do not have a sheath, and occasionally have to be introduced repeatedly, urethral trauma and stricture formation are common sequelae. In addition the irrigation systems usually do not allow for adequate visualization if haematuria develops. The need for a complete change of instruments for subsequent transurethral correction of infravesical obstruction adds to the trauma of the procedure.

All these disadvantages are avoided with the punch lithoclast developed by Mauermayer and Hartung (1976): a reinforced steel cylinder with a 0° telescope and a lithoclast window 15 mm long opening 5 mm proximal to the bladder end is inserted through a standard resectoscope sheath (Fig. 6.2). Under vision, a major segment of the stone is brought into the window and sheared off by moving the lithoclast cylinder against the sheath over a distance of at least the lithoclast window. The forces thus utilized are sufficient to fragment all vesical calculi, provided the size and shape of the stone permits a good grip of the instrument on the stone. Within the wide lumen of the bladder, moving the lithoclast in the longitudinal direction by about 2 cm carries little risk for the vesical wall; the urethra is protected by the sheath. Irrigation is excellent and the entire procedure is performed under optical control, although vision is impaired to a barrel-type view when the lithotrite is opened.

The main limitation of the instrument arises from stones too large to be properly grasped with the lithoclast window. As a panendoscope can be inserted through the same sheath, the technique can be combined with electrohydraulic lithotripsy. Large stones are broken up into smaller fragments, which are then reduced further with the punch. The instrument is ideal for the treatment of stones smaller than 1.5 cm in diameter, which are difficult to disintegrate with electrohydraulic lithotripsy because they tend to bounce away from the electrode. The resectoscope sheath facilitates removal of the stone debris with the Ellik evacuator. The resectoscope is then inserted without changing the sheath for correction of outflow obstruction.

Electrohydraulic lithotripsy
Ever since Goldberg and Rose first utilized the destructive effect of electrohydraulic shock waves for transurethral lithotripsy of bladder stones (Goldberg 1960), this type of stone disintegration has found its major application in the urinary bladder. The physical principles, the equipment and the inherent risks of the technique are described in detail in Chapter 5.

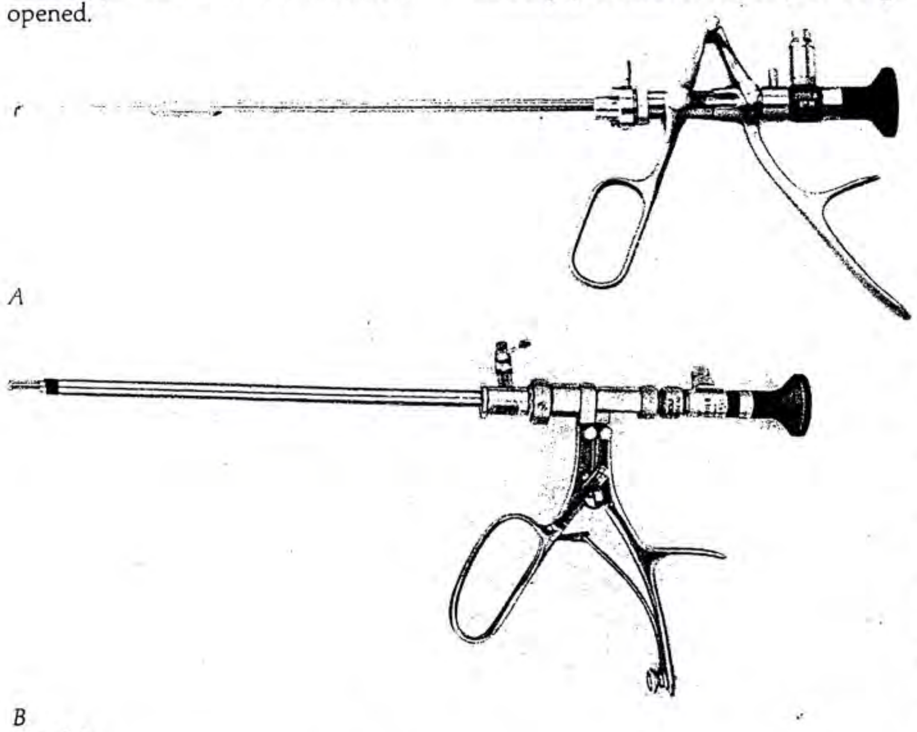


Fig. 6.2
Punch lithoclasts for vesical calculi (*A*—Storz, *B*—Wolf).

The bladder is ideal for electrohydraulic lithotripsy for the following reasons:

1. Its wide lumen permits safe discharge of the electrohydraulic shock wave under visual control, with no problem in keeping the tip of the electrode at least 5 mm away from all vulnerable tissues.
2. There is complete endoscopic control and access to the entire bladder, with virtually no risk of overseeing or not reaching fragments.
3. There is simple atraumatic access for large calibre endoscopes with excellent optical qualities, good irrigation and evacuation properties and working channels that permit the use of 9 F electrodes.
4. Vesical stones tend to be larger, harder (uric acid!) and smoother than other urinary stones and electrohydraulic lithotripsy is by far the most powerful and fastest type of stone disintegration.
5. Transurethral procedures to remove outflow obstruction are easy to combine with lithotripsy and may even be performed through same instrument sheath.

The procedure can be performed under local anaesthesia alone, but as it is usually combined with transurethral surgery of the prostate, general, epidural, or spinal anaesthesia is usually used. The patient is placed in the lithotomy position and prepped and draped as for standard transurethral surgery. In general a 21–23 F panendoscope with a working channel > 9 F is used, so that the 9 F electrode can be inserted without damaging its insulation. As the risk of a 'TUR-syndrome' is significantly lower in the bladder than in the renal collecting system, the standard electrolyte-free solutions available for transurethral surgery are used for irrigation. Electrohydraulic shock waves can also be generated in saline, but the loss of efficacy resulting from this is far more annoying when disintegrating large bladder stones than smaller renal stones (see Ch. 5).

The surgical technique is similar to that outlined in Chapter 5. The bladder should be at least half full during disintegration to reduce the risk of bladder damage within the 5 mm high-pressure zone around the tip of the electrode. The stones are tipped with the electrode and fragmented under vision by bursts of discharges. This should be interrupted by periods of at least 30 seconds to prevent overheating of the electrode; if the electrode becomes too warm to be handled with comfort it is exchanged. Stones behind a large median prostatic lobe or in a bladder diverticulum may be difficult to reach, but with proper filling of the bladder they can usually be manipulated into a part of the bladder where they are under better control. Stones with a rough irregular surface tend to break up faster than smooth, very round stones. The latter may have to be pressed against the bladder wall to prevent them from bouncing away from the electrode and, in this situation, the bladder wall may be damaged inadvertently either by fragments sprayed against the bladder wall, or by being too close to the electrode. The risk increases the smaller the stone is, and it is advisable to reduce the voltage or use the single-shot setting in this situation. Alternatively, the punch lithoclast may be utilized. The stone debris is finally aspirated with an Ellik evacuator and subsequent transurethral surgery is performed as planned. Even if the procedure is terminated after stone disintegration, a urethral catheter should be inserted for at least 24 hours.

Electrohydraulic disintegration is highly successful with minimal morbidity and has become the routine technique for treating bladder stones. In large series the success rates approach 100% with significant complications in less than 2% (Borgman et al 1980, Bülow & Frohmüller 1981). Perforation of the bladder wall and significant extravasation of urine only occurs if the safety precautions outlined above are violated and/or the technique is utilized in abnormal bladders, such as contracted, irradiated bladders, or for stones in diverticula. In the latter situations alternative techniques such as mechanical lithotripsy carry an even higher risk. Minor complications, such as postoperative haematuria or mucosal denudation occur more frequently, but they rarely require any therapeutic intervention. Of course the safety precautions of using electrical equipment of this type must be adhered to, in particular in respect of earthing of both instrument and operating table and of using properly insulated electrodes (see Ch. 5).

Thinner electrodes down to a diameter of 1.6 F are available and can be used through paediatric panendoscopes for treating bladder stones in children. As their insulation is thin, they have to be exchanged frequently to avoid overheating and probe disintegration. The thin lumen of paediatric endoscopes also aggravates aspiration of the fragments. In male infants ultrasonic disintegration with a short ureteroscope may be simpler. Large bladder stones may even be better removed by open cystolithotomy.

Stones in other large cavities filled with urine, such as stones in conduits or pouch neobladders, are removed by the same techniques as bladder stones, i.e. routinely with electrohydraulic disintegration. Only if the stones are extremely soft or are situated in delicate, difficult to visualize positions, such as in nipples of Kock pouches, ultrasonic disintegration with the nephroscope and renal sonotrodes is preferable. Electrohydraulic lithotripsy should also not be used where metal can be contacted, such as for stones formed around metal clips.

Alternative lithotripsy techniques

Ultrasonic lithotripsy. was first utilized for bladder stones and the first ultrasonic lithotrites were designed for transurethral use. Although they were practically free of complications, they proved significantly less effective than electrohydraulic lithotripsy, requiring lengthy treatment with large or harder stones (Marberger 1979). One reason for less satisfactory results was the susceptibility of the early systems to technical failure. Improved generators improved the reliability and in a more recent review of their experience with ultrasonic litholapaxy in more than 400 patients, Hautman et al (1984) reported a reduction in the rate of technical problems from 22% in the first 200 patients to 1% in the last 100 patients. A bladder perforation that was obviously caused mechanically during handling of the somewhat awkward instrument was the only reported complication in the series. Nevertheless, electrohydraulic lithotripsy has become the treatment of choice of bladder stones and the cumbersome purpose-built vesical lithotrites are practically not in use any more. If ultrasonic disintegration is preferred in a specific situation, the ultrasonic lithotrites designed for the nephroscope or ureteroscope can be used.

Microexplosion-lithotripsy. (see Ch. 5) has been utilized clinically by Xui et al (1981) and Watanabe et al (1983) for treating bladder stones. Using a purpose-built cystoscope with integrated forceps to hold the calculus, 2–10 mg of lead azide are ignited in the explosion chamber of a special detonator catheter. With smaller stones the calculus is only tipped with the catheter, in larger stones it has to be inserted in drill holes and as many as six detonations may be needed to fragment the stone. Although microexplosion cystolithotripsy has been shown to provide reproducible results at low morbidity, it is so complicated that its applicability as a routine procedure appears doubtful.

Although, theoretically, *laser lithotriptors* of the Q-switched Nd-YAG type, or flash-light pulsed dye laser type certainly also fragment bladder stones, the energy delivered is simply too low to permit disintegration of large stones within a reasonable period of time. The other lithotripsy techniques mentioned above are more effective and less complex for this purpose.

URETERAL CALCULI: MANIPULATION UNDER FLUOROSCOPIC CONTROL

In at least 50% of all patients seeking medical assistance because of symptoms from urolithiasis, the cause is acute obstruction of the ureter. With 80% of the stones entering the ureter being passed spontaneously (Bandhauer 1970, Ueno et al 1977), expectant therapy has its obvious merits. Prevailing symptoms, significant obstruction, or complications such as infection or an impaired renal function require a more aggressive approach, even if size, shape and position of the stone suggest a high probability of spontaneous discharge. When open ureterolithotomy was the only alternative, the logical step to reduce invasiveness was to use the retrograde transureteral approach. Generations of urologists have worked in this field and the masters were successful in removing over 90% of all ureteral stones requiring treatment with retrograde manipulation (Dourmashkin 1945, Zeiss 1959, Dormia 1982). Extracorporeal shock wave lithotripsy, ureteroscopy and the percutaneous transrenal techniques have totally changed the situation: the majority of ureteral stones that were subjected to retrograde manipulation under radiological control several years ago are today better treated by one of the new techniques. In contrast, with the Steinstrasse extracorporeal lithotripsy has contributed a new legacy to retrograde transureteral manipulation.

The development of image intensification system for continuous fluoroscopic control was a decisive step in improving the safety and efficacy of retrograde manipulation within the ureter, which should not be performed without the availability of continuous fluoroscopic control any more today.

Even with the most scrupulous asepsis, retrograde transurethral-transureteral manipulation may always result in infection of the upper urinary tract, as the anterior urethra is contaminated. The risk is acceptable in the absence of obstruction, but it may result in life-threatening septic complications with persistent obstruction. If retrograde stone manipulation is decided upon, it must therefore lead to an immediate relief of obstruction, either by removing the stone, or inserting a drainage tube. Where this is not achieved, the related kidney should be drained by percutaneous nephrostomy.

For percutaneous antegrade manipulation of ureteral stones, see Chapter 5.

Ureteral catheterization

Bypassing a ureteral stone with a catheter decompresses the collecting system and a Steinstrasse may already dissolve by dislodging the lead fragments with the catheter. In general, stones are not passed alongside the catheter but the dilatation effect is sufficient to promote reliable stone passage after the catheter is removed again. More troublesome is the high risk of infecting the kidney. Unless self-retaining ureteral stents are used, all ureteral catheters have a high risk of being dislodged within hours, once the patient is mobilized. Self-retaining external stents are more reliable and permit better control of the kidney, but they still do not avoid the infection problem, are uncomfortable and require hospitalization of the patient. We only use them in the exceptional situation, where the stone cannot be reached by ureteroscopy because of a tight ureter; after 24–48 hours the ureter is so dilated that ureteroscopy is now practically always successful.

Stenting of the ureter

Internal ureteral stenting is mainly performed prior to ESWL (see Ch. 3), or to secure urinary drainage after ureteroscopy. With calculous material in the ureter, transureteral interventions are usually directed at its removal, rather than just bypassing it. Unless the stone can be flushed back into the kidney, obstructive symptoms may be relieved in this manner if immediate in situ ESWL is not available. Definitive treatment for obstructing stones during pregnancy is also preferably deferred postpartum, after decompressing the kidney with a stent (Loughlin & Bailey 1986). More frequently, an obstructed stent placed prior to ESWL has to be exchanged in spite of major amounts of stone debris in the distal ureter.

In general, stent insertion is difficult in all of these situations. We prefer to use stents that can also be retracted into the direction of the bladder during ureteral manipulation. This can be achieved with a suture passed through the distal end of the stent. More effective and simpler are stents with an integrated positioner that is transected distal to the intravesical coil of the stent after stent insertion, or that is attached with a twist-off connection (W. Rüsch, Rommelshausen, FRG). Movable-core guidewires and stents with a diameter < 7 F increase the chance of bypassing the stone. We prefer polyurethane to silicone stents, because of their higher stability and lower coefficient of friction, which facilitates difficult placement manoeuvres.

Good analgesia is important for success and this is usually achieved with diazepam 0.1–0.2 mg/kg bodyweight and buprenorphine 0.3 mg/kg bodyweight intravenously. In the first attempt, a closed-end stent is introduced with the guidewire in place. Occasionally it will bypass even an apparently impacted stone or a Steinstrasse with ease. Cautious manipulation and fluoroscopic control are essential. To avoid mucosal lesions, resistance should not, under any circumstances, be overcome by force. If the stone cannot be bypassed, the stent is retracted by 1 cm and its tip is slightly curved by pulling the core-wire of the guidewire. Again force is to be avoided. The stone debris of a Steinstrasse may be loosened by pulsed water irrigation with a ureteral catheter first (Sigman et al 1988).

If this fails, passage is attempted with a closed-end 4.5 F stent on a standard guidewire. Lubricant jelly injected into the ureter distal to the stone with a ureteral catheter prior to this attempt improves the chance of success. If this fails, nevertheless, and the calculus cannot alternatively be flushed back up into the kidney (see below), an attempt at bypassing the stone with the soft end of a 0.035 inch guidewire alone is undertaken. To stabilize the floppy tip it may be necessary partially to advance a 5 F angiography catheter over it. If the straight guidewire fails, a 0.035 inch soft guidewire with a floppy J-tip is threaded through the angiography catheter. By manipulating it around the stone, again and again changing its degree of deflection by advancing or retracting the angiography catheter, the stone can frequently be bypassed. Gentle manipulation is of the utmost importance to avoid perforation. With any unclear situation, the ureter is opacified with diluted contrast dye via the angiography catheter. The guidewire is too soft and its surface friction is too high to permit advancing even a well-lubricated stent over it. Instead, it is used to guide the angiography catheter into the ureter proximal to the stone. The J-tip guidewire is then exchanged against a standard stent guidewire or, preferably, a hydrogel-coated guidewire (Mardis & Kroeger 1988). An open-end stent can now usually be advanced over the guidewire. Where even this manipulation fails the stone should be approached endoscopically in the same session.

Retrograde flushing of the stone into the kidney

Stones that cannot be treated by ESWL in situ, or where immediate ESWL is not available but where obstruction should be relieved, should be manipulated back into the kidney. Occasionally, in particular with stones impacted in the proximal third of the ureter with dilatation of the related collecting system, this may easily be accomplished by just touching the stone with a ureteral catheter. We have found a 5 F catheter with an angulated tip most effective for this purpose. Its tip exerts a lever action when twisted. To add extra strength the wire stylet is not removed.

More frequently this fails and the stone has to be flushed back. Standard ureteral catheters do not have an end hole and are therefore poorly suited. For some time we utilized double-lumen balloon-tipped catheters for this purpose. The ureter was occluded with the balloon distal to the stone and the stone flushed upwards with saline injected with a syringe through the second lumen of the catheter, which opened at its tip. Unless the patient is anaesthetized or well sedated, the immediate increase in intrarenal pressure causes severe pain. Correctly inflated, the balloon completely occludes the ureteral lumen. If the stone cannot be dislodged, considerable pressure is exerted on the ureteral wall and we have ruptured the ureter in one patient with this technique.

Today we prefer the polyurethane ureteral dilators used for retrograde ureteroscopy. They have a wide axial lumen that opens at the tip. A dilator of a size that just fits into the ureter snugly is advanced up to the stone over a guidewire. After approximating it as close as possible to the stone, the guidewire is removed and the dilator flushed forcefully with saline and a 10 ml syringe. A special 10 F stone displacement catheter with a second lumen for a 0.038 inch guidewire

(Microvasive, Spencer, In, USA) can be used instead. Its 0.050 inch port also permits rapid injection of viscous jelly, such as anaesthetic lubricant. In our experience this does not improve the dislodgement rate, yet has potential side effects. Clayman et al (1984) recommends CO_2 as a flushing agent, but any advantage of a compressible gas over a non-compressible solution appears dubious.

As soon as the stone is within the kidney, it is treated either by immediate ESWL (see Ch. 3) or percutaneous nephrolithotripsy (see Ch. 6). If this cannot be performed in the same session, it is advisable to insert an internal self-retaining ureteral stent to prevent the stone from migrating into the ureter again. If the ureteral stone does not budge after flushing with a total of 20 ml saline, the technique is abandoned and the stone is removed by antegrade or retrograde ureteroscopy.

Basket extraction under fluoroscopic control

During the last half century over 50 basket-type stone dislodgers have been designed, with 3–6 parallel or helical wires with or without a variety of tapered filiform tips. In central Europe the Dormia basket is the most popular instrument. It is a 4-wire helical basket available 2.5–6 F in diameter, with or without soft filiform leaders; recently a double basket was added to the spectrum, that has a better dilating effect on the ureteral wall (Dormia 1982).

With the basket closed, the stone is bypassed under fluoroscopic control. The basket is then opened and gently retracted to engage the stone. With stones smaller than 8 mm in diameter this is usually achieved without problems. Dormia (1982) does not close the basket thereafter to avoid trapping the ureteral wall. Basket and stone are extracted with slow gentle traction, taking care that the cystoscope, ureteral meatus and stone lie in one line so that the surgeon has direct control of the 'drag' on the basket. In general, immediate extraction is attempted. Gentleness and experience are the hallmarks of success. If the stone is lost, the procedure may be repeated. If stone and basket become fixed and cannot be retrieved, an attempt at loosening the basket and trying again can be performed. Under no circumstances should force be used to overcome an obstacle, if serious damage to the ureter is to be avoided. If the obstacle is at the ureteral hiatus, a ureteral meatotomy may save the situation. It is performed with endoscopic scissors, superior or inferior to the midline of the orifice over a length of 3–4 mm (Drach 1983); electric cutting should never be used with metal baskets. If the basket cannot be removed some authors recommend immediate surgery during the same anaesthetic, whereas others leave the basket in situ for 1–2 days, some even adding a light weight to the basket. If another attempt at extraction fails, the stone has to be removed by open surgery.

The success and complication rate of basket extraction under fluoroscopic control mainly depends on size, shape and position of the stone and the experience of the surgeon. Success rates of over 80% for all ureteral stones have been reported (Dourmashkin 1945, Dormia 1982), but at the price of sometimes very complex manipulation with multiple interventions and adjunctive measures. Most experienced urologists agree with Drach (1983), that a success rate of this magnitude can routinely be achieved for stones < 8 mm in diameter which are impacted in the distal third of the ureter. In most reports, the failure and complication rate increases sharply when higher stones are manipulated (Furlow & Bucchiere 1976). In general, stone basketing is therefore restricted to calculi in the distal ureter. Even with this limitation it has the potential of severe complications, mainly ureteral avulsion and mucosal eversion, particularly in the hands of the inexperienced. In the German-speaking world, loop extraction techniques are therefore traditionally preferred, because of their lower complication rate.

Loop extraction

Two types of loop are utilized for retrieval of ureteral stones. Bow-type loops have one or two drawstrings running outside a short segment of the catheter, usually 10 cm below its tip. By pulling the drawstrings, a side loop is formed that is used to trap the stone. In general, the stone is extracted immediately with the catheter under the same anaesthetic, but it can also be left in situ for some days under gentle traction to be expelled spontaneously. The Davis loop (Davis 1961) is the most widely used loop of this type, in particular in North America. Drach (1983) reports a success rate with this instrument approximately 10% higher than for standard basket extraction with the same range of indications, but a complete absence of severe complications.

In central Europe the Zeiss loop (Zeiss 1959) has almost exclusively been used for retrograde stone retrieval in the last 30 years. It is basically a ureteral catheter with a drawstring, so that the tip of the catheter can be closed to a loop (Fig. 6.3). Under fluoroscopic control, the catheter is passed beyond the stone to the renal pelvis in its open form, and there the loop is completely closed. It is then drawn back to the level of the stone, preferably so that the stone rests within the loop. This instrument is unsuitable for immediate extraction of the stone. It is left in situ, with its free end dangling out the urethra. The patient is mobilized normally. The loop acts like a wedge, gradually dilating the ureter distal to the stone, so that ultimately catheter and stone are expelled spontaneously. Because of this mode of action, the loop is similarly effective if it initially only lies above the stone; as the ureter widens, it gradually engages the stone. As immediate stone retrieval is not attempted, the loop usually is positioned without any anaesthesia in the female, and under intravenous sedation in males. If radiographic control after 48 hours shows little tendency of the stone to budge, a light weight like a haemostat is attached. As the loop drains the collecting system both through its central lumen as well as alongside the catheter, obstruction and infection are rarely a problem. If the loop is not expelled within three days, we usually extract it under a short general anaesthetic, gently pulling the loop. Occasionally it may slip off an impacted stone at this point, so that the procedure has to be repeated. As the ureter is always dilated by this time, we prefer immediate ureteroscopy, if this was not performed in the first place.

In a literature survey, Alken found a mean success rate of this technique of approximately 80% (Alken 1985). Success, however, mainly depends on the position of the stone. In the series reported by Lutzeyer et al (1979), the method failed in over 50% of the stones located in the proximal half of the ureter, whereas it was successful in over 90% of stones located below the iliac vessels. In parallel with this, the number of reinterventions due to loop slippage, the time of hospitalization and the rate of minor complications, such as fever or renal colic, increased sharply with upper ureteral stones. In general, therefore, German-speaking urologists restrict retrograde stone retrieval to stones impacted in the ureter distal to the level of the iliac vessels.

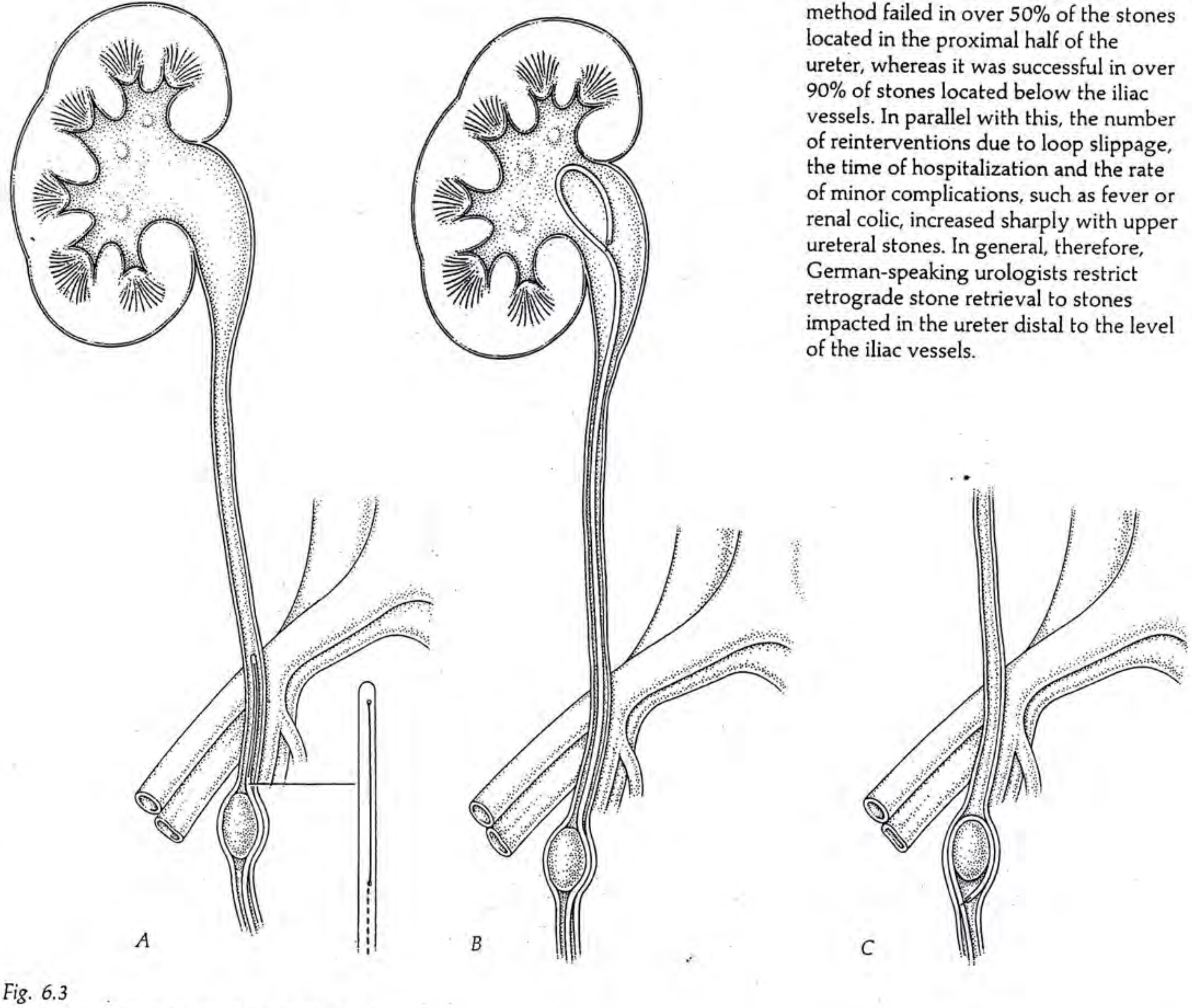


Fig. 6.3
(*A–C*) Manipulation of ureteral stone with Zeiss loop.

The obvious advantage of the end loop is its low morbidity. In reports on 2894 interventions, Alken found only 9 reports of severe complications (0.3%). Although these also mainly comprise ureteral avulsion, the risk is considerably lower than with basket extraction, because the loop usually slips off the stone when undue force is applied. The golden rule, not to attempt immediate extraction, has to be adhered to. The dilating effect of the loop is essential for stone expulsion. Forced traction usually only results in slipping of the loop (Borgman & Nagel 1981). For the same reason, instruments with loops formed from the last 6 cm of the catheter are more effective than smaller loops. The late sequelae of this procedure for the ureter are negligible. In a recall examination of 60 patients that had been subjected to loop retrieval of distal ureteral stones more than 10 years previously, and in whom the loops had in every case been in place for at least three days, no patient showed radiological evidence of a ureteral stricture or vesicoureteric reflux (Marberger & Stackl 1983).

In spite of its low morbidity, the indwelling loop is annoying and uncomfortable for the patient and keeps him in the hospital for several days. As the stones ideally suited for loop retrieval are also ideally suited for ESWL in situ and ureteroscopic extraction, and both are usually less time-consuming, we prefer these techniques wherever possible today. Stone loops have also been disappointing in the management of Steinstrasse problems, because the catheter usually cannot be advanced over the impacted stone debris without risking perforation. Nevertheless, the loop retriever remains an important second-line instrument, as for example when a stone cannot be reached with the ureteroscope.

URETERAL CALCULI: MANIPULATION UNDER ENDOSCOPIC CONTROL (URETEROPYELOSCOPY)

With the development of fibre optical flexible endoscopes, the ureter was immediately recognized as a potential field for the use of this technology. Marshall had already reported in 1964 seeing a ureteral stone in situ with a prototype instrument of this type. In 1970, Takayasu et al presented photographic images of the upper urinary tract obtained with a flexible ureteroscope. These instruments, however, had no irrigation system, working channel, or active steering mechanism and were therefore of experimental interest only. It took another 15 years until these requirements for endoscopic manipulation could be met by flexible ureteroscopes. The clinical breakthrough came with the more or less surprising discovery that the entire ureter and even the renal pelvis were negotiable with rigid instruments. Every urologist has witnessed the occasional situation where a cystoscope can be advanced into an abnormally wide ureteral orifice and ureter. The development of modern rod-lens systems permitted not only a significant improvement of the resolution and light-transmission of rigid endoscopes, but also the construction of significantly thinner and longer telescopes. In 1977, Goodman and Lyon et al (1979) routinely started to inspect the lower third of the ureter with paediatric cystoscopes. Perez-Castro et al (1980) added the final step: using a purpose-built 9 F endoscope with a working length of 39 cm that was basically an extended paediatric cystoscope they showed that the entire ureter and even the renal collecting system were accessible to rigid instrumentation under vision. Supplemented by the parallel development of percutaneous nephroscopy, upper urinary tract endoscopy became a clinical reality.

Anatomical considerations

The insertion of endoscopes into a muscular tube of up to 34 cm length (Gosling et al 1982), which is not in line with the direction of the port of entry, i.e. the urethra, can only be achieved because of two specific properties of the ureter: its mobility and distensibility. Both are required, whether rigid or flexible endoscopes are utilized.

The urinary collecting system is attached to the kidney by the thin diaphragm of connective tissue that originates from the fibrous capsule of the kidney and seals the renal sinus. It blends with the adventitia of the collecting system and is completely fused to it at the level of the minor calyces so that these are fixed to the papillae. The calyces join to form the renal pelvis with a wide range of variability both in size and shape. It ultimately changes shape into a funnel and becomes the ureter. As this point is, in general, not defined by an anatomical landmark, it is better termed the pelvi-ureteric region than the pelviureteric junction (Gosling et al 1982). The proximal point of insertion of the ureter is therefore not fixed, but rather semi-mobile and this effect is increased by the overall mobility of the kidney within Gerota's fascia.

The ureter then courses downwards in the retroperitoneal space along the psoas muscle, crossing the vessels at the level of the bifurcation of the common iliac artery. It then gradually bends medially and anteriorly from the pelvic wall to reach the base of the bladder. Its main arterial blood supply comes from tributaries of the renal and superior vesical arteries, but, with high variability, also from the aorta and branches of the aorta. The venous drainage uses the same route. The vessels run along the loose adventitia of the ureter, which also carries the lymphatic and nerve supply. As this structure is only very loosely attached to the posterior peritoneum the ureter is extremely mobile over its entire length (Fig. 6.4). In spite of its immediate vicinity to some extremely delicate structures, like the duodenum and vena cava on the right and the jejunum and colon on the left, injury of these when the ureter is perforated is extremely unlikely as they are mobile too.

The ureter enters the bladder obliquely, creating an intramural segment which, to a large degree, courses submucosally and ends at the ureteral orifice. The musculature of the terminal ureter is arranged in an almost entirely longitudinal direction. It blends without interruption into the superficial musculature of the trigone that reaches into the prostatic fossa down to the verumontanum (Fig. 6.5).

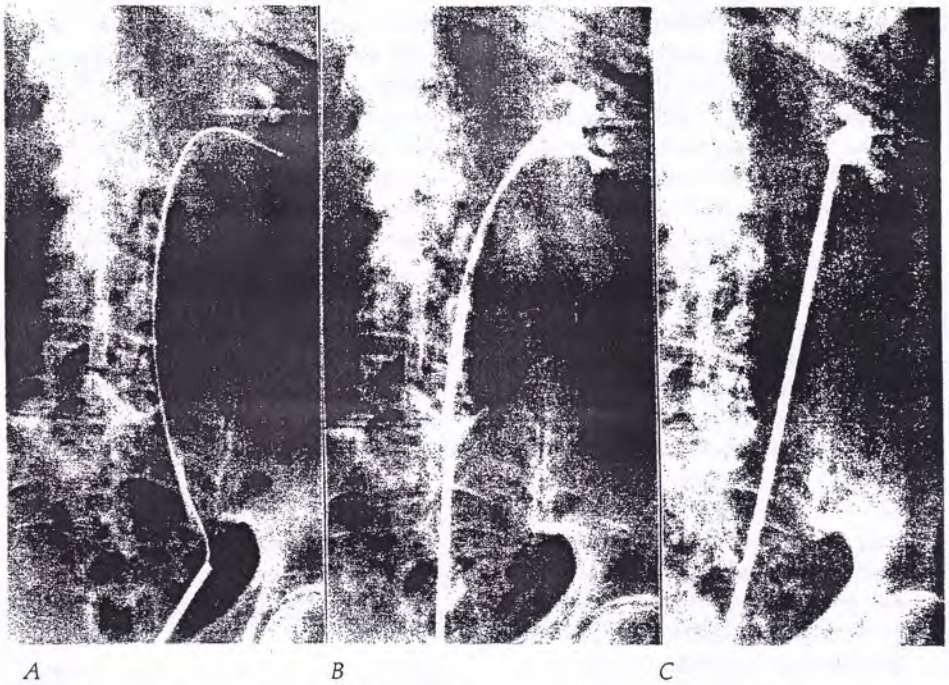


Fig. 6.4
(*A–C*) Mobility of ureter at rigid ureteroscopy.

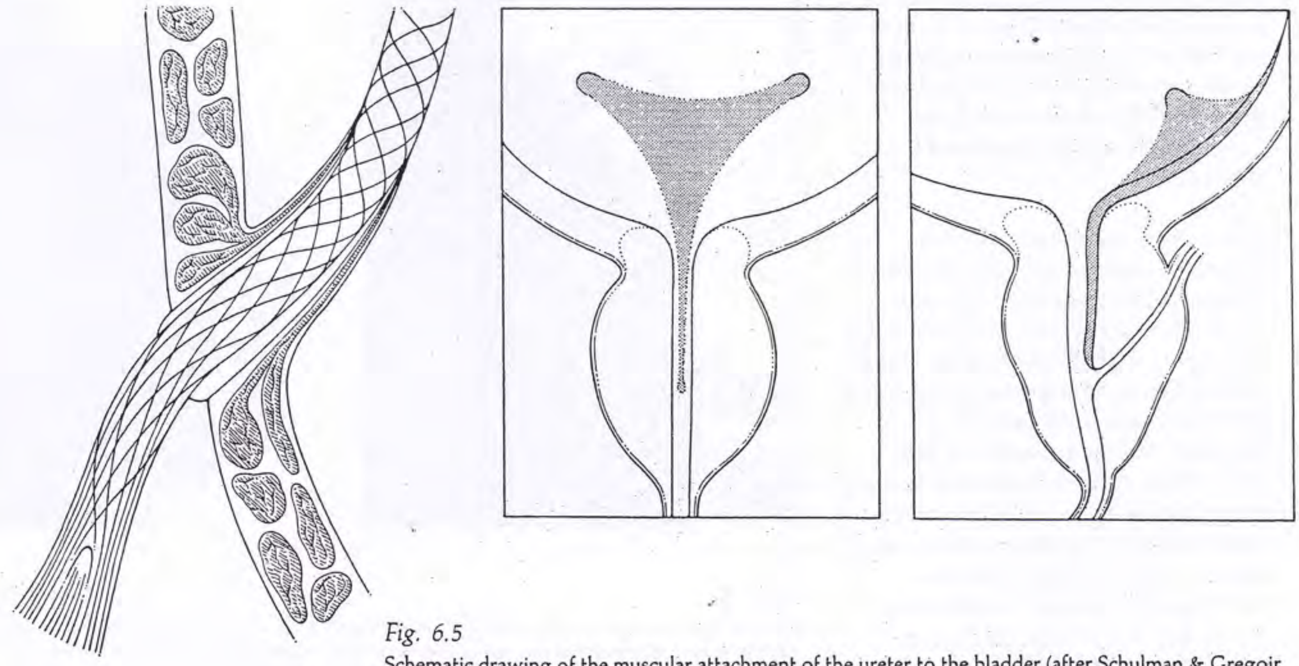


Fig. 6.5
Schematic drawing of the muscular attachment of the ureter to the bladder (after Schulman & Gregoir 1977 and Gosling et al 1982).

This anchors the ureter rather firmly to the trigone and bladder neck and is the main factor in preventing vesicoureteric reflux (Tanagho et al 1968, Schulman & Gregoir 1977). The intramural segment of the ureter is bolstered by the bladder musculature to give support during bladder filling, and this effect is increased by a tube of vesical musculature extending onto the distal ureter and blending with the ureteral adventitia. This structure, termed Waldeyer's sheath, is separated from the muscular layer of the ureter by loose connective tissue. As the ureteral muscle fibres circumvent the ureteral orifice along its posterior and lateral aspect, the medial wall of the intramural ureter is extremely delicate, with a very thin muscular layer in its more proximal part and only mucosa and submucosal tissue in its distal part. It is obviously the site most vulnerable to false passage. Although the musculature is stronger along the posterior circumference, it is still thinner than higher up the ureter. As the intramural ureter is relatively immobile because of its fixation to the trigone, overzealous retrograde instrumentation may result in shearing it off at this point. In general, this will be incomplete and Waldeyer's periureteral musculature will still hold the ureter in place, but retrograde catheterization usually becomes impossible.

The ureteral wall is formed of an internal mucosal layer, a middle portion of musculature and an outer tunica adventitia that contains the vasculature and nerve supply. The muscular fibres show different arrangement patterns at different levels of the ureter, but together with the collagenous and elastic fibres in the subepithelial layers they basically form a mesh net that adapts ideally to changes of the ureteric lumen. In the collapsed state, the ureteral lumen appears capillary and star-shaped and surrounded by an impressive multilayered ureteral wall. In the dilated state the ureteral wall is distended to a structure 1–2 mm thick, with a multifold increased diameter of the lumen. This not only results from distention of the longitudinal folds of the ureter, but also the urothelium's ability to stretch without rupturing. Every urologist has experienced impressive dilatation of the ureter upon acute obstruction, with complete recovery within hours after the relief of obstruction.

The amount of distension a ureter can be subjected to without damage is of crucial importance for intraureteral endoscopy, where the situation differs from clinical acute obstruction by occurring far more acutely. Hasun et al (1990) dilated canine ureters with teflon dilators increasing in diameter in increments of 0.33 mm. The baseline lumen of the ureter was defined by the size of a dilator which could be passed without significant resistance. More and more force had to be applied with subsequent dilatation until the structures suddenly gave and a nephrostomogram showed longitudinal splitting of the ureter and dye extravasation. This almost uniformly occurred with dilators just exceeding twice the size of the baseline lumen. Long-term follow-up showed a high chance of late stricture formation if this occurred, whereas no significant late sequelae were noticed with less pronounced dilatation (Fig. 6.6). The authors concluded that normal ureters could be subjected to acute dilatation of about double their normal lumen without adverse effects. Ford et al

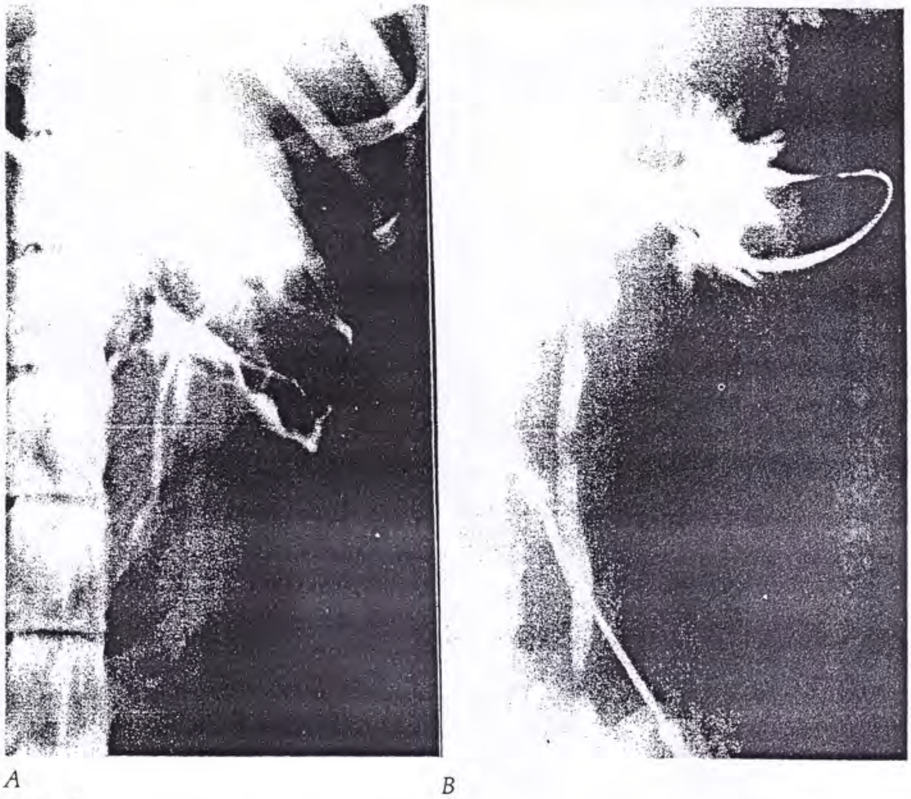


Fig. 6.6

Nephrostomograms of a canine ureter (*A*) immediately after acute antegrade dilatation with tapered dilators to about three times its normal diameter, resulting in longitudinal splitting and dye extravasation, and (*B*) 3 months later, showing a severe stricture.

(1984) came to almost the identical conclusions with a similar study in rabbits and Boddy et al (1988) in guineapigs. Most human ureters admit an 8 F catheter with ease, so that this can be considered a baseline value. If the experimental observations also apply to the human, this would suggest an upper limit of safe acute dilatation at about 16 F.

Intermittent dilatation with teflon dilators results in considerable shearing forces, in particular on the epithelial lining of the ureter, and it may thus be more traumatizing than concentric balloon dilatation. The time within which the ureter is dilated is obviously another important factor; with very rapid dilatation the chance of tissue disruption is certainly higher than when the tissue can adapt to the strain forces. This was confirmed by experimental balloon dilatation of porcine ureter by Clayman et al (1987). Slow dilatation up to 24 F was well tolerated, whereas rapid dilatation within less than 10 seconds resulted in significant extravasation and periureteral haematoma. By 1945, Dourmashkin had already provided clinical evidence that the proximal ureter can be dilated safely to 24 F, provided this was done gradually with balloon catheters.

At autopsy, a normal adult ureter has an external calibre of about 5 mm and its lumen shows no significant landmarks. In vivo there usually are three distinct narrow sites where passing calculi tend to become impacted and where passage of an endoscope may meet more difficulty: the ureteropelvic region, the segment where the ureter crosses the pelvic brim in close proximity to the iliac artery, and the ureterovesical junction. There is considerable variation in the degree of narrowing encountered individually and, in particular, the two proximal sites may frequently be passed endoscopically without discernible problems. If the ureteropelvic region appears tight endoscopically, this frequently results from angulation of the ureter with the instrument against the more mobile pelviureteric junction, which in addition tends to be pushed downward during respiratory movement (Huffman & Bagley 1988). Non-distensible, tight portions of the ureter at the pelvic brim more commonly appear to be of functional origin, perhaps as a muscular reaction to continuous pulsation in the nearby vicinity. As the ureter also changes its direction at this point, telescoping of the ureter as the endoscope is advanced may also contribute to what appears to be a significant stenosis.

In vivo, the intramural portion of the ureter is the most narrow segment of the ureter. The main contributing factor seems to be the high tone of the surrounding bladder musculature, which is needed to prevent reflux, but the oblique course of the ureter certainly is also responsible for the frequent impaction of ureteral stones at this point and difficulties in entering the ureter with instruments. In general, the orifice has a diameter of about 3 mm, i.e. an 8–9 F catheter can just be inserted. If a catheter with an angulated tip is used and it is twisted lightly to follow the natural course of the ureter, the size of a catheter the ureter will just accept increases by 1–2 F. The medial and upper semicircumference of the orifice is usually the most obstructive part of the intramural ureter and it tends to become injured first. It contains no musculature and moderate tears rarely result in reflux (Stackl & Marberger 1986a). Only an incision opening the intramural ureter will result in reflux in about 40% of the patients (Sigman et al 1988). Sterile reflux probably has no adverse effects on the upper urinary tracts (McLean et al 1980), but a formal ureterotomy should be avoided when ureteroscopy is planned. Endoscopic orientation becomes difficult within the cut edges of the orifice, and this results in a high chance of false passage between Waldeyer's sheath and the ureteral musculature.

RIGID URETEROPYELOSCOPY

Equipment

Since Perez-Castro et al (1980) first presented a purpose-built rigid ureteropyeloscope, the field has witnessed a technical explosion. Basically, equipment development went through three generations of instruments: a first generation of ureteropyeloscopes with working ports for flexible instruments; it was followed by endoscopes permitting intraureteral instrumentation with rigid instruments such as ultrasonic lithotripsy under vision; they were succeeded by ureteropyeloscopy systems with a wide range of interchangeable sheaths, telescopes and working attachments for the entire range of ureteroscopic surgery. These advances were paralleled by the development of special instruments, such as extremely thin instruments down to a diameter of 6.5 F with one or two working channels, a wide variety of instruments incorporating cutting knives and diathermy loops, and short ureteroscopes designed for working in the distal half of the ureter only. Considerable attention was directed towards designing instruments with less traumatic tips and eyepieces mounted laterally, angled, or adjustable to personal comfort.

This presentation cannot cover the entire spectrum of commercially available instruments, but rather reflects personal experience and habits. The advantages offered by third generation instruments, namely the versatility of adapting the same set of instruments to almost any clinical situation, are such that all precursor instruments appear outdated. Most manufacturers provide sheaths for these systems with a tip diameter ranging from 10.5 to 13.5 F, depending on what they are intended for. We almost exclusively use 11.5 F sheaths, which can be inserted into the ureter without needing too much dilatation, yet permit ultrasonic lithotripsy under direct vision with a 1.9 mm probe. As the sheath costs a fraction of the telescope, it is advisable also to procure a 10.5 F sheath for diagnostic purposes and a 12.5 F sheath for better irrigation and more effective ultrasonic lithotripsy in difficult situations. The sheaths should have an atraumatic bevelled tip and accept both standard telescopes and offset telescopes for ultrasonic lithotripsy (Figs 6.7–6.9).

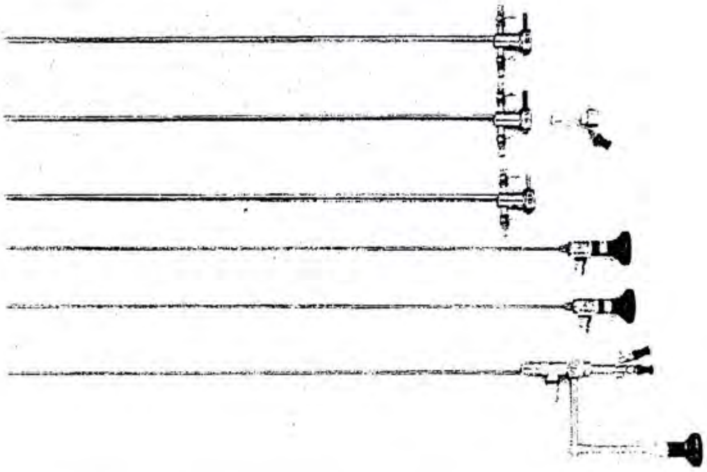


Fig. 6.7

Standard Wolf ureteroscope with interchangeable 10.5–12.5 F sheaths and 5°, 70° and offset telescopes.

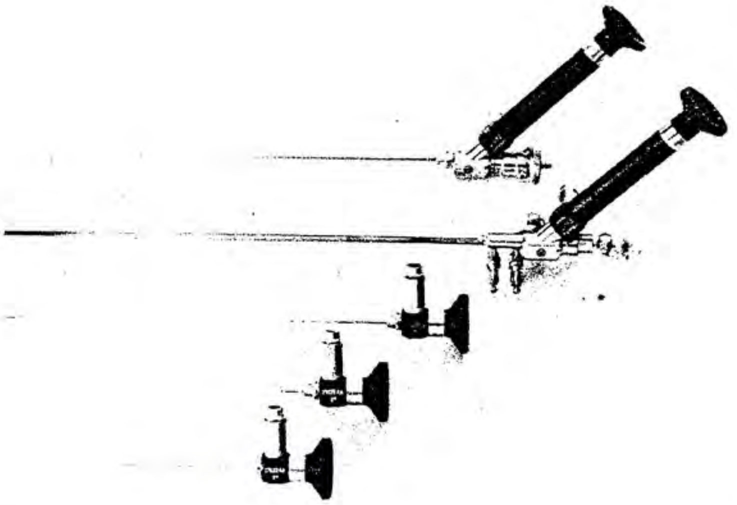


Fig. 6.8

Storz interchangeable offset, 70°, 6° and 0° telescopes for use in 10.5–13.0 F ureteroscope sheaths, integrated 12 F ureteroscope with offset telescope, straight instrumentation channel and continuous flow irrigation systems.

Standard telescopes are in general available with a 0°–5°, 25° and 70° angle of vision. Antegrade lens systems are certainly the workhorses and essential and all offset-telescopes provide this angle of vision. Seventy degree telescopes were designed for work within the renal pelvis and we had found little practical use for them, but the 25° telescope is occasionally helpful for orientation in very tortuous ureters. The offset telescope is indispensible for stone management; if necessary, it can even be used for diagnostic ureteroscopy, although the offset eye-piece may occasionally be impeding. A standard antegrade telescope is certainly also to be recommended and a 25° telescope is helpful.

Since stones in the proximal half of the ureter have become the domain of ESWL, ureteroscopic stone manipulation is largely limited to the distal half of the ureter. Short ureteroscopes with a working length of 28 cm are adequate for this purpose (Fig. 6.10). They are easier to manipulate and, as they bend less, they have better optical qualities and provide better irrigation and easier manipulation through the working ports. Because of their shorter length they are sturdier and less liable to be damaged during cleaning and sterilization. At the present time, we use them in more than 90% of all ureteroscopic stone manipulations and, in females, the entire length of the ureter may even be covered. Moreover, we have found short ureteroscopes extremely helpful for endoscopic surgery in the urethra especially in children. For a centre where a major amount of ureteroscopic stone work is anticipated, we would, at the present time, consider a full set of sheaths from 10.5 to 13.5 F, an antegrade standard telescope and an offset telescope of the standard length, and a set of 10.5 to 13.5 F sheaths and an offset telescope of the short length as appropriate basic equipment. Where bridges are required to fit telescopes to sheaths, these, of course, also have to be supplied.

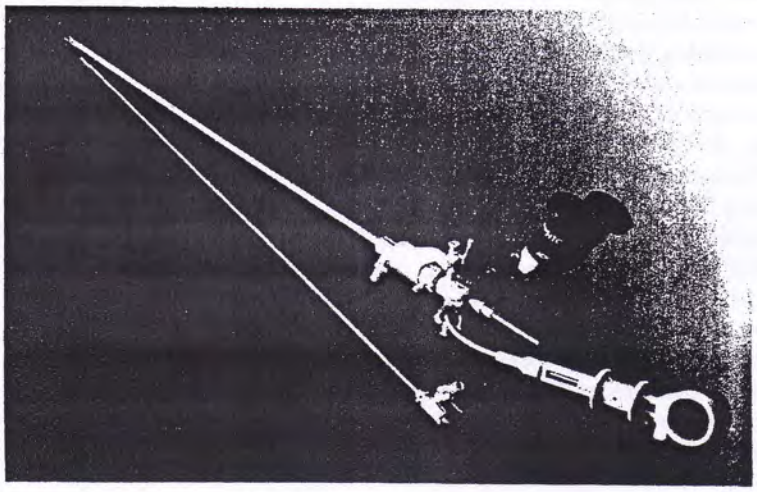


Fig. 6.9

ACMI 'goose neck' 12.7 F ureteroscope with flexible eyepiece, offset telescope and 5 F working channel.

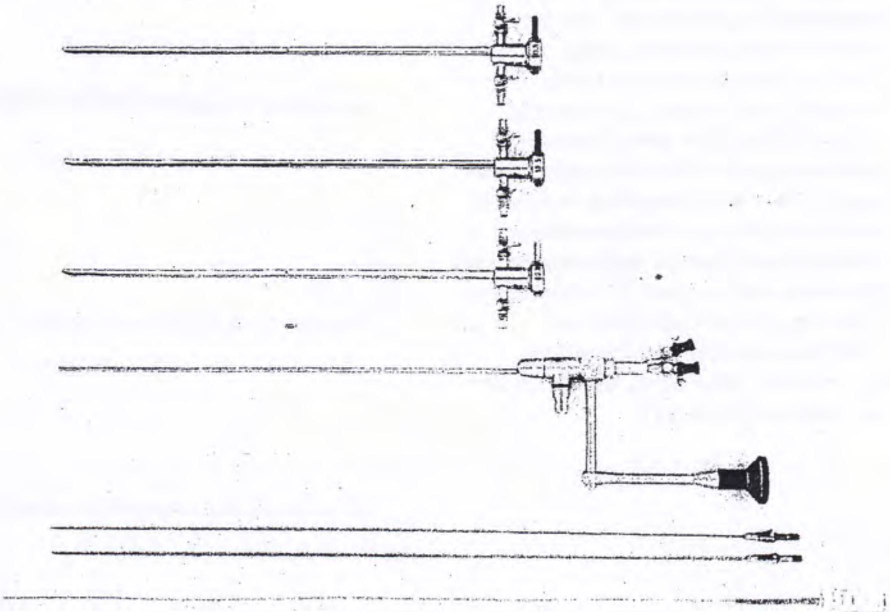


Fig. 6.10

Short (32 cm) Wolf ureteroscope with interchangeable 10.5–12.5 F sheaths, 1.5 and 1.9 mm sonotrodes and 3.3 F electrode for use through the working channel.

In ureteropyeloscopes with integrated telescopes, the space otherwise needed for containing the various parts of interchangeable endoscopes is saved, so that instruments of considerably smaller calibre can be constructed. Although a 9.5 F instrument may still have a 3.5 F working channel accepting a 3 F basket, instruments of this type are of more use for diagnostic ureteroscopy than for surgical manipulations (Fig. 6.11). The exception is laser lithotripsy, which only requires the insertion of quartz fibres down to a diameter of 200 micrometres. Miniureteroscopes of 6.0–7.2 F are now available for this purpose; they have working ports for irrigation and the laser fibres (Fig. 6.12). At this diameter, bending of the instrument cannot be avoided and with a standard rigid rod-lens system this would result in an immediate loss of view; by integrating a fibre-optical system in the semirigid shaft of the instrument a sharp, clear view is obtained in spite of deflection of the distal end to up to 2 inches (Fig. 6.13). On the other side of the range, special surgical indications may require larger instrument diameters, mainly for better irrigation and instrumentation. Resectoscope sheaths, ureterotomes and operating endoscopes with continuous flow irrigation and an Albarran deflecting lever for manipulating electrodes or laser fibres have an outer tip diameter of 13–14 F.

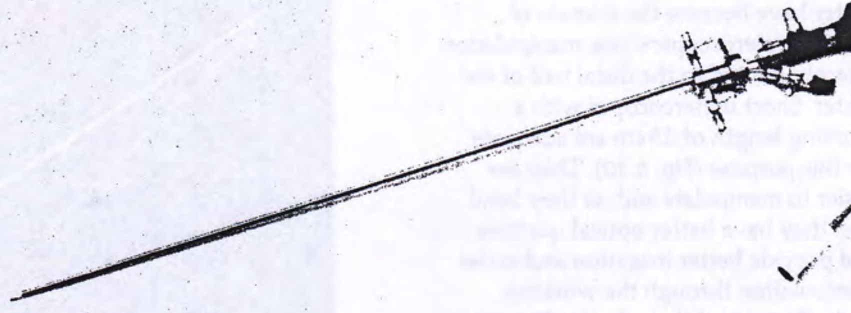


Fig. 6.11
Integrated 32 cm 9.5 F Wolf ureteroscope with 3.5 F working channel and a 3.3 F electrode for electrohydraulic lithotripsy inserted.

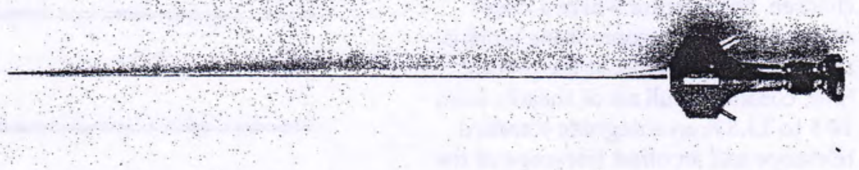


Fig. 6.12
7.2 F Candela miniscope with two separate working channels for irrigation and laser fibre.

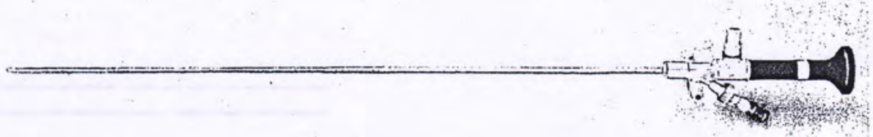


Fig. 6.13
6.0 F Wolf miniureteroscope with one working port for irrigation and laser fibre.

Seeing the stone without having the possibility to remove it is one of the most frustrating experiences of an endoscopist. Accessory instruments are therefore just as important as the ureteroscopes. They must comprise a wide variety of baskets and forceps for extracting the stones, and a variety of guidewires and dilatation instruments. Unless the ureter is dilated excessively, stones larger than 4–5 mm along their shortest diameter cannot be extracted and have to be disintegrated in situ. Ultrasonic disintegration is our standard approach and an adequate selection of sonotrodes from the solid rod type to a 1.9 mm probe, depending on the endoscopes used, should be available (Fig. 6.14). In general, manufacturers offer screw-on sonotrodes that are bolted to the same transducers used for percutaneous ultrasonic lithotripsy (see Ch. 4). If electrohydraulic disintegration is preferred, a supply of 3.5 F electrodes must be in supply and are used with a generator adapted to electrodes of this size (see Ch. 4). A full range of ancillary instruments, from ureteral catheters over stents to dilatation instruments, must be available. Finally, ureteroscopy should only be performed under fluoroscopic control and with free availability of percutaneous drainage techniques, if the need should emerge.

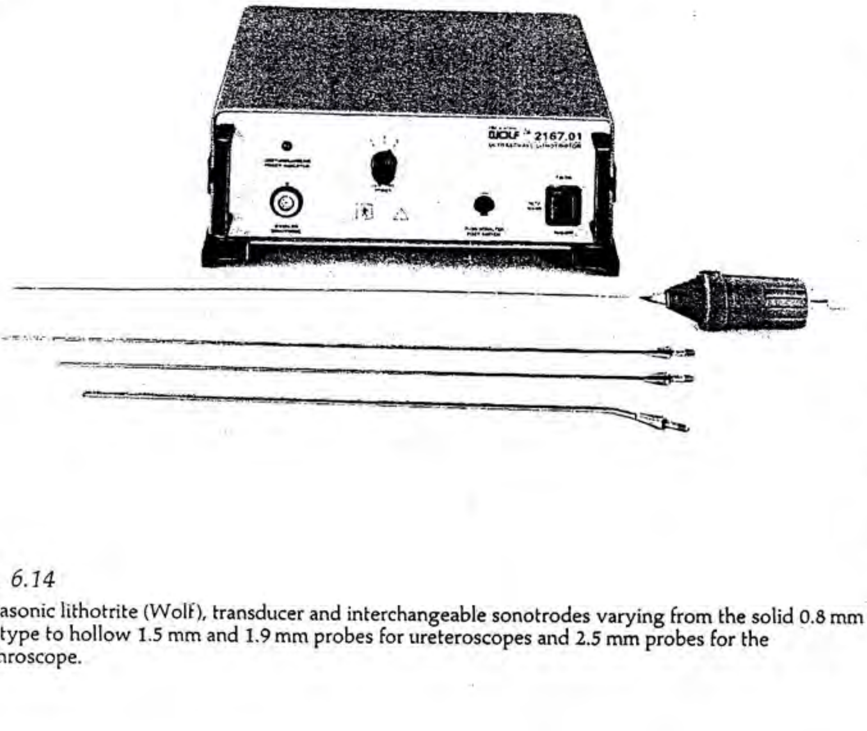


Fig. 6.14

Ultrasonic lithotrite (Wolf), transducer and interchangeable sonotrodes varying from the solid 0.8 mm rod type to hollow 1.5 mm and 1.9 mm probes for ureteroscopes and 2.5 mm probes for the nephroscope.

Patient preparation and positioning

Some authors perform ureterorenoscopy under intravenous sedation and analgesics only. As full relaxation of the striated pelvic and abdominal musculature facilitates the procedure significantly and, in contrast, an apprehensive moving patient may prevent it, we routinely perform endoscopic procedures in the ureter under general anaesthesia. No special preoperative preparation other than routine for procedures under anaesthesia is required. We have, however, experienced severe septicaemia when manipulating infected and obstructed collecting systems. Urinalysis and a urine culture is therefore routinely obtained. If any pathological micro-organisms are identified, they are treated with appropriate antimicrobial agents according to sensitivity testing for at least 48 hours. A urine culture may remain sterile in the presence of a calculus completely obstructing an infected kidney; if a severely obstructed collecting system is diagnosed after a recent history of fever, chills and other symptoms suggestive of infection, we prefer first to relieve obstruction with a thin percutaneous nephrostomy and treat infection appropriately for some days before the endoscopic procedure is performed. The need for a percutaneous nephrostomy may occur during ureteroscopy at any time. The laboratory studies pointed out in Chapter 5 are therefore routinely obtained. The position of the stone is once more documented by a plain film immediately before anaesthesia is induced.

Fluoroscopic control is essential during ureteroscopy. This can be achieved with a C-arm and postioning the patient on a table with a radiolucent centre piece. We prefer fluoroscopy units specifically designed for uroradiology. They provide the optimal combination of fluoroscopy and still image facilities with simple mechanical movement of the table to focus any part of the urinary tract. As a disadvantage for the surgeon, they have overhead tubes with a higher risk of scatter radiation. With the use of freeze-image techniques, careful coning of the fluoroscopy field, protective shielding and scrupulous use of fluoroscopy the problem can be minimized. Tables of this type permit an immediate change to a percutaneous procedure during the same anaesthetic if this should become necessary. Moreover, if a second generation lithotriptor is used with an integrated shock wave unit, the procedure can be combined with ESWL in the same session, for example when a ureteral stone is flushed back into the kidney during ureteroscopy (Fig. 6.15).

The exaggerated lithotomy position, the flat supine position with the legs spread for transurethral manipulation and a modified lithotomy position with either the ipsi- or contralateral leg abducated and extended have been recommended. They all aim at facilitating ureteroscopy by aligning the course of the ureter to the urethra and providing enough manoeuvring space for the surgeon. As the ureter changes its course both in the sagittal and frontal direction with significant individual variation, no single position is ideal for every situation, as Angus and Webb (1988) have shown. We routinely place the patient in a lithotomy position with the contralateral leg flexed as usual, and the ipsilateral leg abducated and extended (Fig. 6.15). This, hopefully, reduces the lateral and dorsal excursion of the ureter below the pelvic brim. The most difficult segment of the ureter to pass, however, is the intramural and pre-vesical segment. It frequently courses in an almost horizontal direction and this requires ample room for the endoscope and the surgeon's head and this is probably the most important result of good positioning. We feel that this is best achieved with the contralateral leg up, because the surgeon can work under the knee of the patient. Perez-Castro (1988) recommends the contrary and seems to have the same results. We have also performed ureteroscopy with both legs up and with both legs down, so that the issue may well be rather unimportant and perhaps left to the preference of the individual.

The patient is prepped and draped as for transurethral surgery. Working in a potentially obstructed upper urinary tract requires careful aseptic techniques, and a scrub nurse is needed to tend to the well organized instrument table. It should contain all instruments needed from the beginning of the procedure, including syringes, guidewires and dilatation equipment as well as saline and diluted contrast dye in sterile bowls. The surgeon should routinely wear a mask that covers the mouth; if the nose is also covered, fogging of the lenses becomes an insoluble problem. An unsterile assistant must be in the room to provide any additional equipment needed as well as to control the irrigation system. We routinely use saline for this purpose, which is supplied by gravity irrigation from two disposable 3-litre bags via a twin irrigation system as used for trans-urethral surgery. The bags are suspended by an electrical hoist, so that the irrigation pressure can be regulated by elevating or lowering the bags.

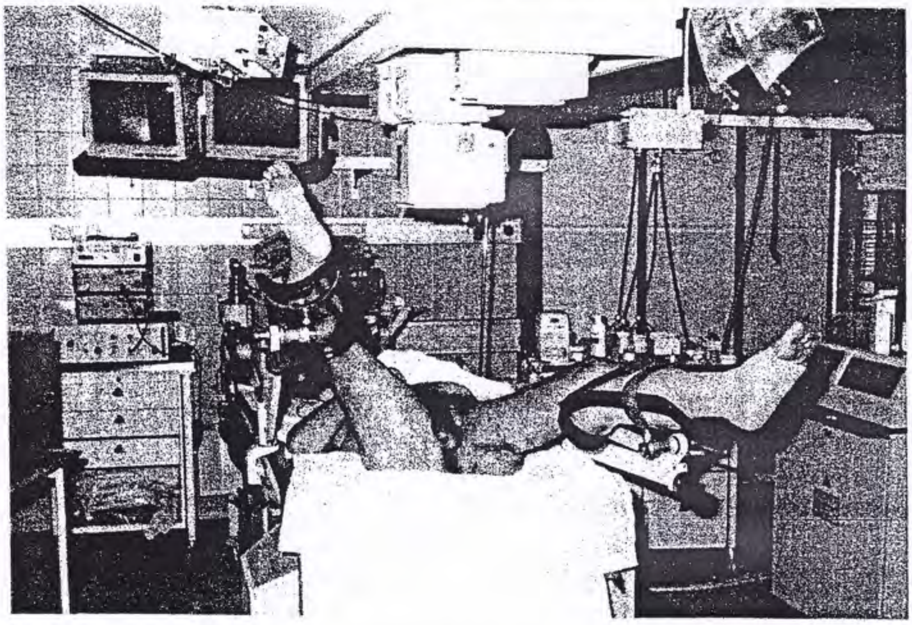


Fig. 6.15

Patient positioned and draped for ureteroscopy on Lithostar multipurpose lithotriptor (Siemens); note irrigation fluid.

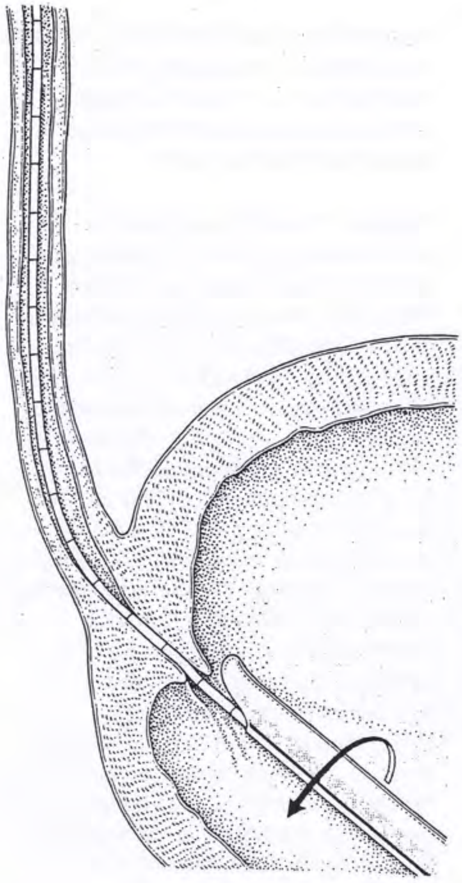
Inserting the endoscope into the ureter

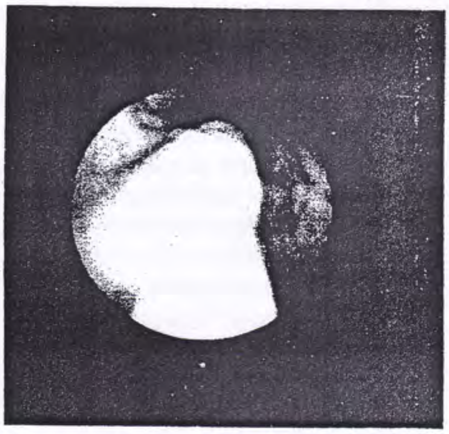
Successful advancement of the endoscope into the prevesical ureter is one of the cornerstones of success for this technique and, in the hands of beginners, the most common reason for failure. With the individual variability of the ureterovesical junction, it obviously cannot be achieved with one standard method only. A spectrum of techniques must be available, both in respect of equipment and experience of the surgeon. They are selected according to the individual situation, always bearing in mind that failure of one method must not preclude the next step if a complete failure of the entire intervention is to be avoided. The golden rules of this principle are gentleness in tissue handling, adequate fluoroscopic and endoscopic control, and safeguards against losing the ureteral lumen with security guidewires or catheters. Based on personal experience in well over 1000 ureteroscopic procedures in the last 6 years, we have designed a step-by-step procedure that in our hands has reduced the failure rate of ureteroscopy to less than 8%.

With the ureteral stones being subjected to endoscopic management today, our routine instrument has become the short 11.5 F ureteroscope with an offset telescope and a 5 F working channel. Its long version and their 12.5 F counterparts are only occasionally used for selected cases. We see no need for larger calibre rigid instruments, and hence no need for ureteral dilatation > 13 F. Admittedly, instrumentation would occasionally be simpler with wider ureters, but with the excellent techniques for intraureteral stone disintegration available the higher risk of complication and complexity of more extensive dilatation does not appear justified (Ford et al 1984, Newman 1988, Hasun et al 1989). Each year we handle about 400 patients with ureteral stones needing a therapeutic intervention at our institution. With free availability of second generation ESWL and ureteroscopy along these guidelines, we have not performed a ureterolithotomy in the last year.

At least 75% of all ureters can be entered with 11.5 F rigid endoscopes without formal dilatation (Webb & Fitzpatrick 1985a, Stackl & Marberger 1986a, Schmöller et al 1987, Fuchs 1988, Perez-Castro 1988). The key to this is the alignment of the intramural portion of the ureter with the direction of the urethra by elevating the medial lip of the ureteral orifice. This can be achieved in an elegant way with a specially curved wire deflector, which is advanced through the ureteroscope and turned 180° (Webb & Fitzpatrick 1985a). Newer third generation ureteroscopes with beaked atraumatic tips permit a simpler approach. Endoscopy is started directly with the short 11.5 F ureteroscope, which can be manipulated almost like a cystoscope. In contrast to standard size ureteroscopes, the ureteral orifice can usually be identified without any problems. A 4 F ureteral catheter is inserted through the working port and up the ureter into the renal pelvis. To give the catheter appropriate rigidity, the stylet is not removed.

The endoscope is now advanced directly onto the orifice and turned 180°. This transposes the ureteral catheter to the medial aspect of the ureteral orifice which is thus elevated and transformed into a gaping hole (Fig. 6.16). Using gentle pressure, the instrument is now advanced under vision along the lumen, over the ureteral catheter.





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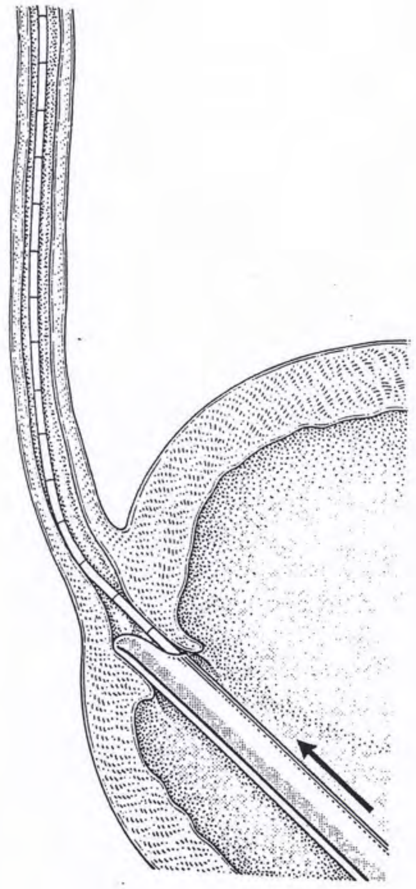
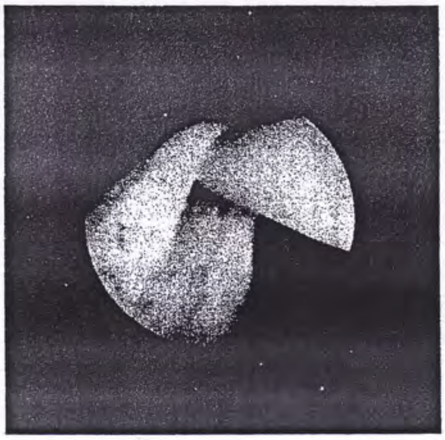


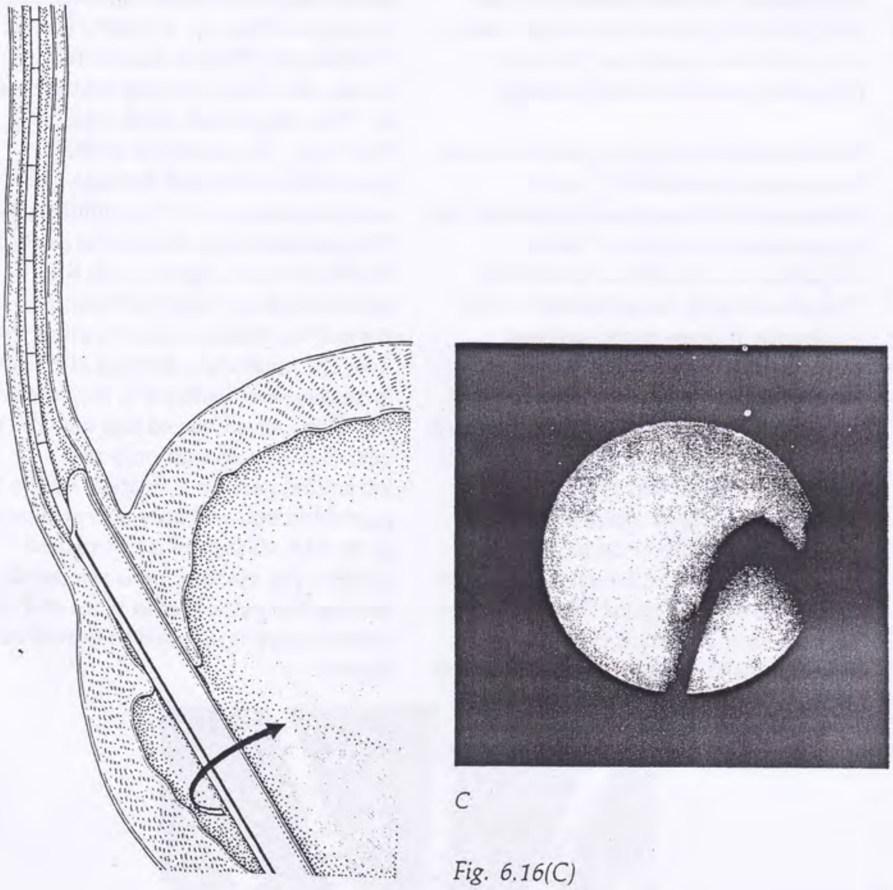


B

Fig. 6.16

Inserting the ureteroscope into the ureter without dilatation: (*A*) the ureter is catheterized and the ureteroscope rotated 180°; (*B*) the catheter elevates the medial lip of the orifice, so that the ureteroscope can be inserted into the slit like lumen under direct vision; (*C*) once the intramural portion is passed, the endoscope is rotated back again to the normal position.

Good irrigation, either with the help of a perfusion pump (see Fig. 6.21), or with a 20 ml syringe connected to the outflow port of the instrument (Fig. 6.17) is most important at this phase. The lumen, or at least the ureteral catheter, are then clearly visible and followed, gently turning the instrument to make up for the oblique direction of the ureter as the intramural portion is crossed. The ureter widens immediately outside the ureteral hiatus. The instrument is now rotated back to the original position and advanced as usual.



C

Fig. 6.16(C)

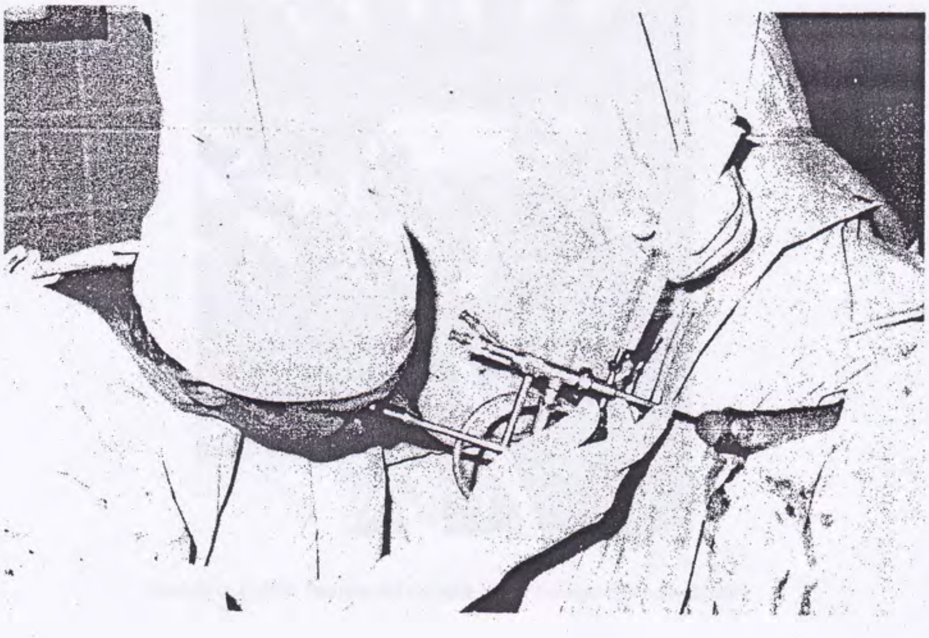


Fig. 6.17

Forced irrigation with a syringe on the inflow tap.

Elevation of the medial lip of the orifice may be simpler, if the ureteral catheter is inserted with a cystoscope, before the ureteroscope is introduced into the bladder. As it then courses outside the endoscope, it can be used like a lever on the medial side of the orifice when the ureteroscope is turned 180°. Conversely, it is more difficult to visualize the catheter within the intramural ureter. We therefore only use this technique if the ureteral orifice cannot be visualized, which may occur with either the long or the extremely thin ureteroscopes.

A major problem that may occur is the inability to advance a ureteral catheter up the ureter. If it is trapped in the mucosa of the intramural portion and force is applied, the ureter may be perforated and this should in all circumstances be avoided. If resistance is noted, we usually remove the catheter and bend its tip manually over a distance of 1 cm, with the stylet still in place. With appropriate gentleness, and provided the ureter has not been damaged previously, the intramural portion can now usually be passed with slight twisting of the catheter along the ureteral course. If this fails, the stylet is pulled back some centimetres to soften the tip of the catheter. If the catheter still cannot be passed, a 0.035 teflon or hydrogel coated guidewire with a straight floppy tip is inserted. It, too, may catch the ureteral mucosa and perforation can occur if too much force is applied in spite of its soft tip; by directing the guidewire with the help of a 5 F open-ended ureteral catheter (Rüsch, Waiblingen, FRG) or angiography catheter slightly bent at its tip, it can usually be brought to follow the lumen and be directed up into the renal pelvis. The guidewire can be used like the ureteral catheter for opening the ureteral orifice. As it is more prone to kinking, it is safer to advance the endoscope over it than alongside it. In our experience the ureter can almost always be intubated with one of these techniques. The ureteroscope should preferably not be inserted under vision only, without a guide, as this very frequently leads to a false passage.

If the ureteral catheter or guidewire has been passed successfully, but the intramural ureter appears too narrow for the endoscope in spite of forced irrigation, it needs formal dilatation. This should only be performed over a guidewire. If open-ended ureteral catheters are used routinely they are easy to exchange against a guidewire. Most are too thin to accept the standard 0.035 guidewire. An 0.025 guidewire is therefore inserted and the ureteral catheter exchanged against a thin angiography catheter under fluoroscopic control, which is then used to insert the 0.035 guidewire. Although slow balloon dilatation probably is the least traumatizing form of dilatation, we usually use serial teflon dilators (Cook Urological, Spencer, In, USA; Rüsch, Waiblingen, FRG) or coaxial teflon dilator sets (Cook Urological, Spencer, In, USA; Angiomed, Karlsruhe, FRG; Fig. 6.18). The distal end of the guidewire is threaded through the working port of a 23 F panendoscope. The panendoscope is introduced into the bladder and aligned with the ureteral orifice. Under endoscopic control the dilators are now advanced over the guidewire, starting at 8 F and increasing the diameter in increments of 1 F. They are advanced just into the prevesical ureter, so that only the intramural portion is dilated. As the 23 F panendoscope will only accept dilators up to 12 F, dilatation is not carried further. The cystoscope is removed, leaving the guidewire in place and the ureteroscope is inserted as described above.

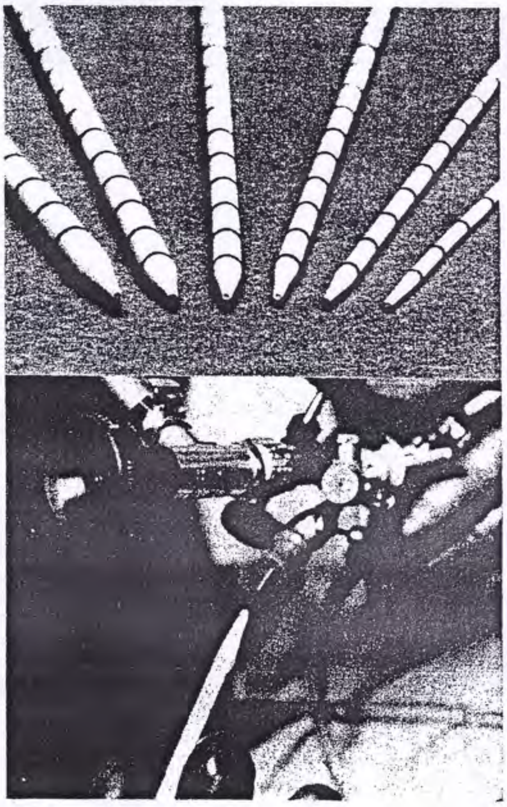


Fig. 6.18
Guidewire and tapered teflon dilators for ureteral dilatation (Rüsch).

Coaxial teflon dilator sets can be used under fluoroscopic control only, but we believe that dilatation under vision reduces the shearing forces because of better directional control of the instruments. Access systems with sheaths are only rarely used, such as for flexible ureteroscopy (Newman 1988). Although they facilitate intraureteral manipulation, their insertion may be quite traumatical in rigid ureters and the extra 2–3 F of dilatation needed does not routinely appear justified. Early in our experience we used metal bougies with an olive-shaped head on a flexible steel shaft that were inserted intermittently over a guidewire, but they proved considerably more traumatic than teflon dilators. We have no experience with multibead metal dilators or telescopic metal dilators worked with a screwing mechanism to straighten the ureter (Pflüger 1986), but they also appear rather traumatic. Dilators not passed over a guidewire should never be used because of the high risk of associated false passages.

Where these techniques fail or a dilatation is expected to be difficult, such as after previous surgery, balloon dilatation is indicated. We use high pressure, non-elastic balloons 5–10 cm in length that inflate to a size of 12 or 16 F. Any angioplasty catheter that fulfils these requirements and can be advanced over a guidewire is suitable; our usual choice is the Olbert angioplasty catheter (Meadoc Surgimed, 3660 Stenlöse, Denmark) that tolerates up to 12 bar (174 psi) maximum inflation pressure and can also dilate fibrous scars. We do not reuse the balloons and carefully evacuate all air from the balloon prior to its use. It is inserted over the guidewire, so that the proximal radiopaque mark showing the upper end of the balloon is within the prevesical ureter, and the mark of the distal end of the balloon within the bladder. The balloon is filled gradually so that it expands over a period of about 1 minute. This can be achieved manually with a 20 ml syringe, but it is safer to use one of the commercially available inflation devices. We have found the Leveen inflation device (Microvasive, Spencer, In, USA) most helpful for this purpose (Fig. 6.19). The piston of its 10 ml syringe is advanced by a screwing manoeuvre, so that the balloon is filled very gradually and steadily. A pressure gauge should routinely be used between inflation syringe and balloon to avoid excess pressure and balloon disruption, and possible damage to the ureter. The balloon is inflated under fluoroscopic control to detect waisting due to a narrow, more resistant segment. When this is observed, inflation is slowed to give this segment a chance to dilate also. After the balloon has reached its complete inflation diameter over its entire length, it is left in place for another 2–3 minutes. It is then completely deflated and removed, leaving the guidewire in place. The ureteroscope is inserted as described above.

Inserting the ureteroscope may be most difficult with distal ureteral obstruction. If a stone is impacted in the intramural ureter and it cannot be catheterized, a meatotomy with the electric knife directly onto the bulge of the stone is usually the treatment of choice. Stones in the distal ureter can, however, today be treated very effectively by ESWL in situ, with less morbidity than ureteroscopy (El-Faquih et al 1988, Marberger et al 1988), so that the actual number needing endoscopic manipulation is low. Occasionally they can be bypassed with a guidewire or the ureteral catheter, or a floppy guidewire can at least be looped into the ureter distal to the stone to a length of 3–4 cm, which is usually enough for inserting the ureteroscope. The main problem arises with the treatment of Steinstrasse, where retrograde passage of a ureteral catheter or guidewire is difficult because of the tightly packed fragments. If the lead fragment is impacted in the ureteral orifice, a ureteral meatotomy with endoscopic scissors may be the treatment of choice (Sigman et al 1988).

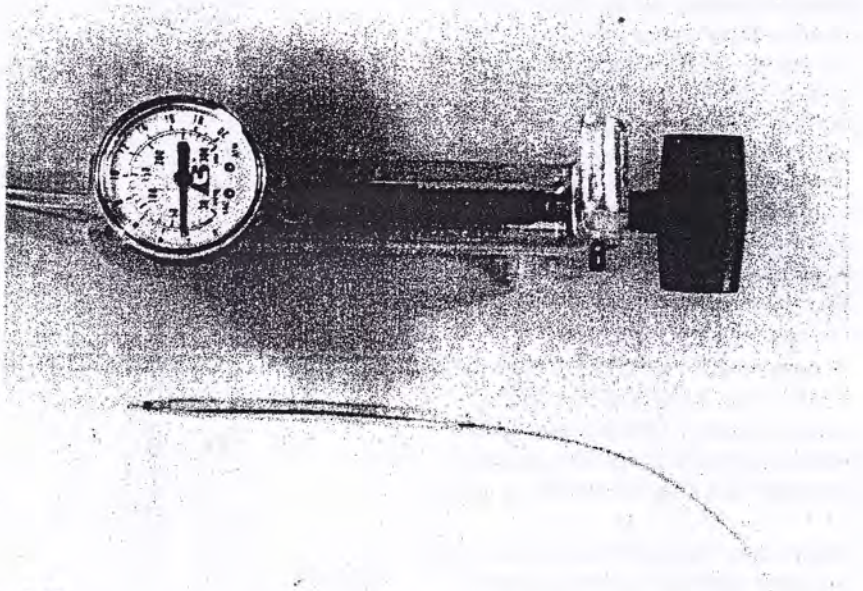


Fig. 6.19

Olbert angioplasty catheter (10 cm balloon length, diameter of inflated balloon 15 mm; Meadox, Surgimed) and Leveen syringe (Meditech) for pressure-controlled balloon inflation.

With obstruction at a higher level, retrograde catheterization with an open-ended catheter and pulsed water irrigation frequently resolves the fragment jam (see Ch. 3). If retrograde ureteroscopy is still needed, a floppy guidewire is advanced as far into the ureter as possible, carefully avoiding perforation. The thinnest available short ureteroscope is advanced alongside it, under vision, with maximum irrigation but without formal dilatation. If a false passage was avoided at the attempts of passing the catheter, the stone can usually be visualized rapidly and now a second guidewire can frequently be passed by the stone under visional control. By 'nosing' with the endoscope the stone may be dislodged slightly, so that this is facilitated. By this time the intramural ureter is so dilated that a larger calibre ureteroscope can be inserted onto the stone even without a guide. Lasertripsy with the miniscope is ideal for this situation.

Reaching the stone
Once the intramural segment of the ureter is passed, the instrument can be advanced within the distal third of the ureter without major problems. Until the stone is reached, the open-ended ureteral catheter or guidewire remains in place to serve as a security line, and to help co-ordinate fluoroscopic and endoscopic orientation. Occasionally the ureteroscope may inadvertently be angulating the ureter, so that it cannot be followed upward endoscopically. This is immediately seen at fluoroscopy and corrected by aligning the ureteroscope to the ureter, if necessary by retracting it slightly. We do not routinely place a second safety guidewire, as we feel it more often impedes intraureteral manipulation than it helps.

Irrigation is imperative and usually easy to achieve with an 11.5 F instrument. Gravity irrigation is routinely used, but this may have to be supplemented by an occasional forced irrigation with a 20 ml syringe connected to the outflow port, with the inflow port closed. This is preferable to pressurizing the bags with irrigation fluid as it is easier to control and avoids overdistension.
Instruments < 13.5° usually do not have a continuous flow irrigation system. With insufficient drainage alongside the instrument, flow may come to a standstill and vision is impaired. This can immediately be corrected by pulling back the ureteral catheter so that its tip is about 1 cm ahead of the ureteroscope, and using it as an outflow channel (Fig. 6.20). Clots or small stone fragments can likewise be flushed away from the endoscope with this technique, if necessary even by intermittent flushing with a syringe.
Perez-Castro designed special roller pumps (Fig. 6.21) for this purpose that permit forced irrigation at preset flow rates and pressures, with a safety valve in case higher pressures are reached. They provide flow rates of up to 400 ml a minute, but the ureter is sufficiently dilated by 200 ml per minute and pressures around 100 mmHg for rapid advancement of the ureteroscope. The irrigation fluid drains alongside the ureteroscope and a urethral catheter has to be inserted to prevent overdistension of the bladder. Perez-Castro (1988) has not noted adverse effects from a short-term increase of intraureteral pressure and Eshghi (1988) has found hydraulic dilatation to be the least traumatic method for rapid dilatation of the ureter. Nevertheless, the large amount of fluid being pumped into the upper urinary tract is cause for concern and we do not

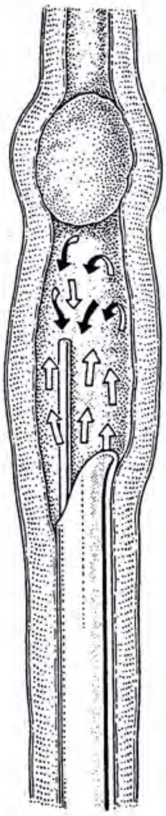


Fig. 6.20

Improved vision by continuous flow irrigation via an open-ended ureteral catheter inserted through the working channel.

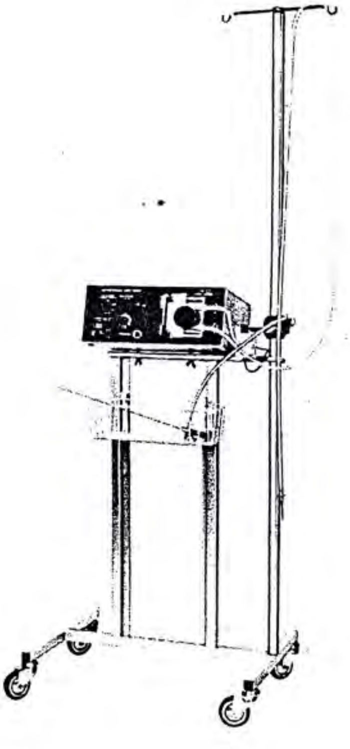


Fig. 6.21

Pressure-controlled roller pump for hydraulic dilatation of the ureter (Ureteromat, Storz).

routinely use pumps. At low flow rates the roller pump also tends to exert a pulsatile-type perfusion, which is annoying for orientation. If difficulties arise, however, hydraulic dilatation is a very efficient solution to most problems.

Provided that the ureter is not scarred or fixed by previous surgery, irradiation, or periureteral pathology, the level of the iliac vessels is usually reached rapidly. At this point, which may often be recognized by pulsations seen endoscopically, the ureter tends to be narrower or at least to respond less to hydraulic dilatation. As the endoscope engages the mucosa circumferentially, it folds up in front of the instrument and may in fact telescope the ureteral wall (Fig. 6.22). This narrows the segment even further. Persistent force may lead to perforation or avulsion of the ureter. Noticed in time, the situation can frequently be avoided by optimal alignment of the ureteroscope to the course of the ureter, retracting it for 1 or 2 centimetres and advancing it again carefully under forced irrigation. Occasionally, the bevelled tip of the instrument has to be nosed and turned slightly with gentle pressure. If all fails, the segment has to be dilated. Unless there is a formal stricture, it is usually amenable to balloon dilatation directly through the ureteroscope. Leaving sheath and guidewire in place, an angioplasty 12 F catheter is introduced through the sheath, over the guidewire and through the narrow segment. The balloon is positioned with the help of radiopaque markers and inflated as described above. In general, the segment can now be passed without problems. We have found dilatation with telescope or serial dilators more traumatizing at this level and they also require removal of the ureteroscope.

If the narrow segment cannot be passed in spite of hydraulic and balloon dilatation, it is usually better to insert an indwelling ureteral stent and to continue some days later, than risking severe damage of the ureter. In case a perforation is suspected, a retrograde ureterogram is obtained by injecting diluted contrast dye through the inflow port of the ureteroscope. If there is a reasonable chance of being able to remove the stone without too much trauma, the procedure may be continued in spite of extravasation. Otherwise it is wiser to insert an indwelling stent and to repeat the procedure some days later. The stent almost immediately abolishes peristalsis and dilates the ureter. After 24 hours the narrow segment can usually be passed without problem.

Of course narrow segments may occur at any level of the ureter and in particular from oedema at the stone bed. The stone may just be visible but the instrument cannot be advanced over the oedematous site. If the situation cannot be managed with hydraulic dilatation and repeated careful advancing and retracting of the instrument, it may be simpler to flush the stone back into the kidney rather than formally dilate the segment. It can frequently be dislodged with a ureteral catheter under vision, even if this failed under fluoroscopic control. Alternatively, an ultrasonic probe can be used. With forced irrigation, the stone is almost always successfully dislodged. A stent is inserted and the stone is treated by ESWL, either in the same session or at another time.

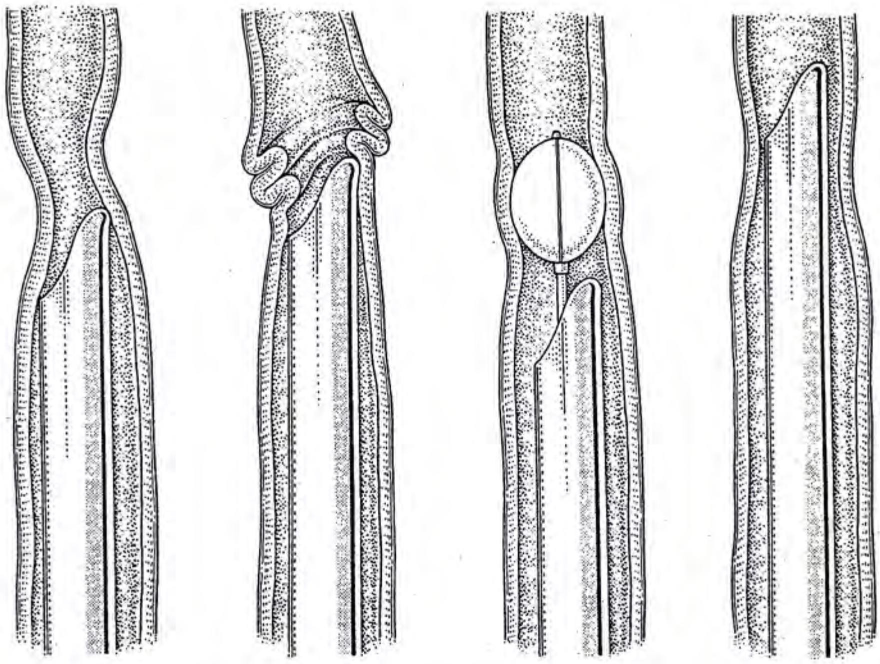
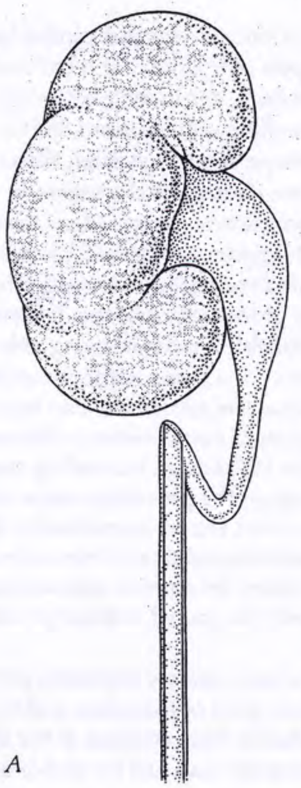
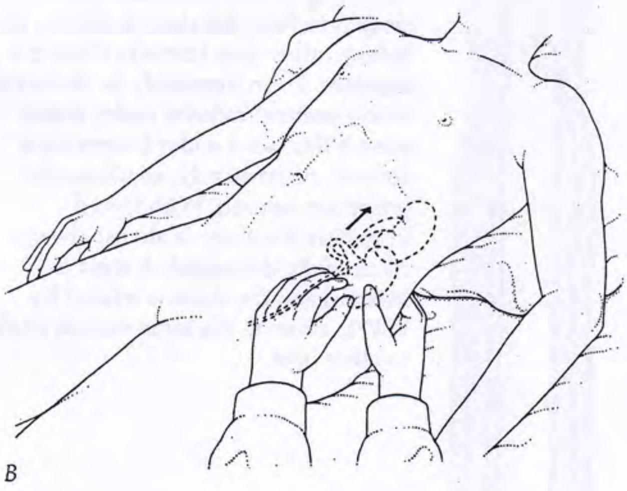


Fig. 6.22

To avoid telescoping the ureter at narrow segments, these are balloon-dilated through the sheath of the endoscope, after the telescope is removed.



Tortuosity of the ureter may also impede passage when advancing the ureteroscope. It usually results from obstruction and hence occurs above the narrow segment, but in megaureters of infravesical or intrinsic origin the entire ureter has a wide lumen. As the endoscope is advanced up the ureter kinking may even be increased, resulting in folds and bends of up to 180°. The proximal lumen is lost from vision and perforation may ultimately result. The problem mainly occurs in the proximal ureter, in particular just below the ureteropelvic region (Fig. 6.23). Frequently the kink can be straightened out by retracting the instrument some centimetres and advancing a more rigid ureteral catheter as a path-finding aid. If the proximal lumen cannot be identified, the 25° telescope is helpful. With inspiration the kidney moves downwards and this also increases ureteral angulation. By placing the patient in a moderate Trendelenburg position and having an assistant push the kidney cephalad beneath the costal margin, the catheter can usually be slipped into the renal pelvis during expiration. Once it is in place, the endoscope can usually be advanced over it without major problems, especially with forced irrigation. If the catheter cannot be inserted directly, this is attempted over a J-floppy 0.035 guidewire, using the open-ended catheter to stabilize the tip of the guidewire as it is slowly manipulated up the ureter. The ureter has to be straightened for this manoeuvre. If the endoscope is held firmly by the lower ureter, this can occasionally be achieved by simply retracting the instrument. Otherwise the ureter is occluded with a double-lumen balloon catheter, which is inserted through the sheath of the ureteroscope after removal of the telescope. Its balloon is inflated to a point that permits slight traction without dislodging the balloon. As the ureter straightens the guidewire is threaded through the second lumen of the catheter and up into the kidney.



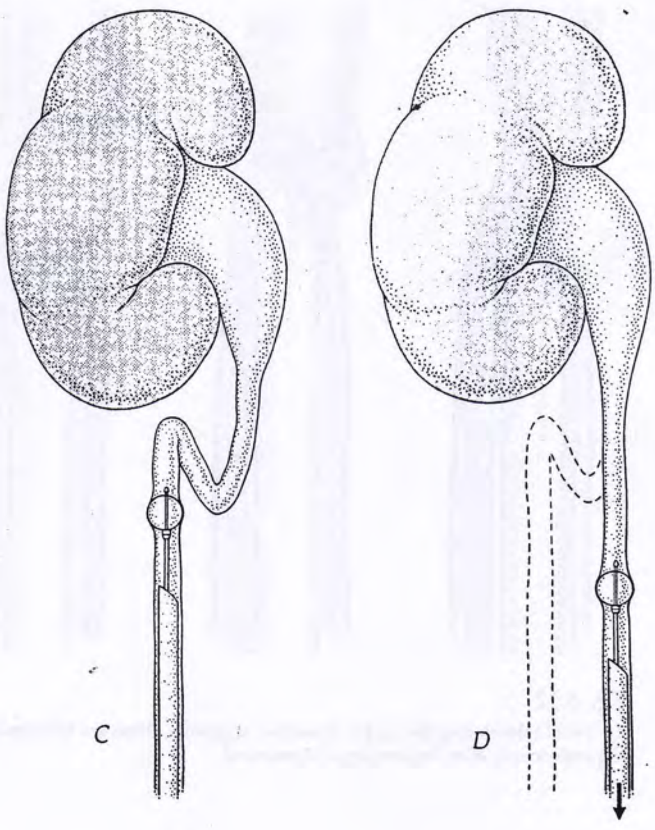


Fig. 6.23

Kinks in tortuous ureters (*A*) can be straightened out (*B*) manually or (*C, D*) with balloon traction, so that a rigid guidewire can be advanced over the kink.

Rigid ureteroscopy requires at least some mobility of the ureter. Where this is impaired by periureteral scarring from previous surgery or periureteral pathology, a higher chance of failure has to be anticipated (Fig. 6.24). As the ureter cannot be aligned, manipulation is usually more forceful resulting in a high risk of perforation. Ureters coursing through a region that was subjected to irradiation are particularly vulnerable. Preoperative radiographic findings are misleading, however, in respect to the degree of fixation of the ureter and frequently ureteroscopy is surprisingly simple. To reduce the amount of intraureteral manipulation, we like to insert a self-retaining internal ureteral stent for some days prior to ureteroscopy in these situations. This usually abolishes the need for ureteral dilatation and provides better vision, as there is less mucosal damage. Thinner endoscopes are, of course, simpler to advance, but the standard rod-lens systems are immediately out-focused as they bend; with undue force, they may also break. Instruments combining properties of rigid and flexible endoscopes offer some advantage here, but in general this is the domain of flexible ureteropyeloscopy. With scarring of the distal ureter the proximal ureter is better approached in the antegrade direction (see Ch. 5).

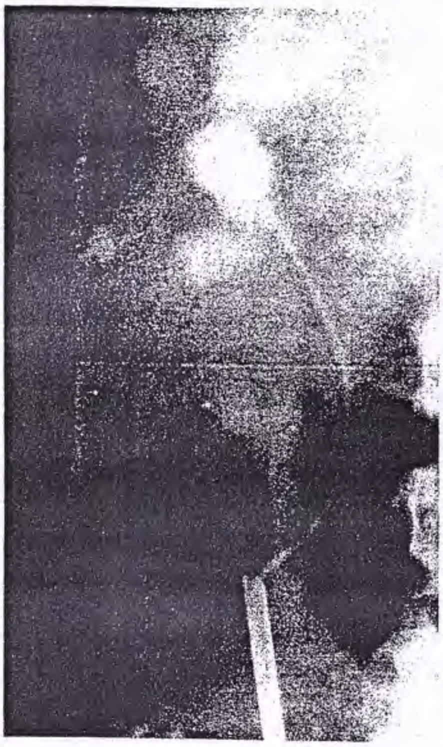


Fig. 6.24

Ureter 'frozen' by previous surgery, so that it cannot be aligned to the rigid endoscope.

Extracting stones

Once the stone is reached it also has to be removed. With smaller stones it would appear simplest to insert a rigid alligator forceps, grasp the stone and extract it together with the instrument. A variety of purpose-built forceps are available for this manoeuvre, among them 'king size' forceps that permit grasping a stone of a diameter up to 6 mm. Although Perez-Castro (1988) considers these instruments the first choice for stone extraction, we are not so satisfied with them. The stones tend to slip from the prongs as they are extracted, in particular if they are jagged and the ureteral orifice is rather tight. It may also be difficult to grasp an impacted calculus and the long jaws of the instrument may injure the ureter. In order to pass through a 5 F working port, they have to be extremely delicate, yet they must still provide adequate grip on the stone. Because of the lever action applied on the jaws of the forceps, they break easily at their common joint when force is applied on the stone. We therefore use these instruments mainly for removing the lead fragments of a Steinstrasse, which usually dissolves rapidly thereafter. We have not found flexible triradiate graspers helpful during retrograde manipulation. Flexible alligator forceps are usually useless because of their small dimensions.

The stone basket is our standard instrument for stone extraction. As working ports of ureteroscopes rarely exceed a diameter of 5 F, and this may be reduced even further by bending, only baskets 4.5 F or smaller should be used. One hand control of basket advancement and retraction and the removability of the sheath and handle are essential. A variety of baskets of the helical or flat wire type that fulfil these requirements are available. We prefer the Segura flat wire baskets (Microvasive, Spencer, In, USA) (Fig. 6.25). Lateral wire movement is eliminated, allowing for more definite stone manipulation and the basket opens more effectively in the undilated ureter. A variety of baskets should be available, including four- and six-wire baskets without and with filiform tips. We usually use working lengths of 90 cm and regular size baskets with 2 cm between wires. Four-wire baskets are used for larger stones, six-wire baskets mainly for removing stone debris after ESWL.

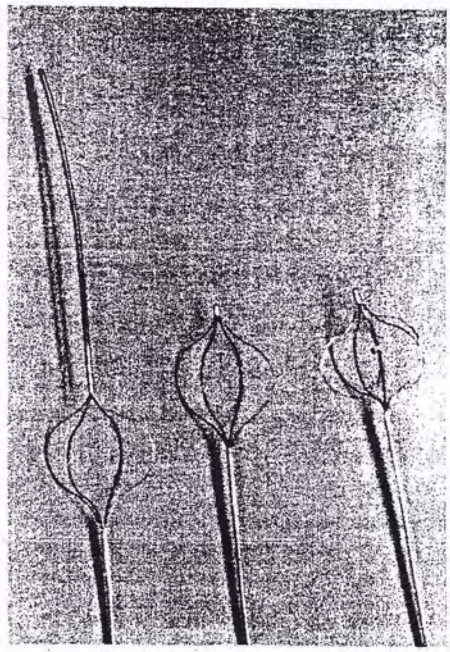


Fig. 6.25

Segura flat wire stone baskets (Microvasive).

Even very impacted stones usually have a small window between ureteral wall and stone. Under endoscopic control it is quite simple to bypass the stones at this point. To avoid dislodging the stone upwards, irrigation should be as low as possible at this time and all manipulation has to be performed swiftly and carefully. We routinely use flat wire baskets without a tip and unless the stone is very impacted it suffices to advance the sheathed basket to the lower rim of the stone. The basket is then slowly opened under vision along the assumed window between stone and ureteral wall. Its parting wires partially dilate the ureter and also usually immediately trap the stone. With the basket open the stone is fully engaged, if necessary with some to and fro and even twisting movements (Fig. 6.26). If helical baskets are used or the stone can only be bypassed with the filiform tip or the sheathed basket, the basket is opened above the stone. This should be performed as gently and as rapidly as possible to reduce the risk of flushing the stone upwards. The stone is engaged by retracting the basket and not before this is fully achieved is the risk of flushing the stones upwards eliminated.

The basket is closed around the stone under vision, carefully avoiding trapping of mucosa. The stone should be in the basket so that it presents with its smallest diameter. If this is not achieved, the basket is reopened and the stone is re-engaged until it is in an optimal extraction position. Time spent for good stone alignment is time well spent, because it facilitates extraction and ultimately ensures success. If multiple stones or stone debris from a Steinstrasse are extracted, we feel it is safer to leave the basket open. The stone is approximated as close to the tip of the ureteroscope as possible and basket. Stone and endoscope are then slowly extracted. The course of the ureter is followed by appropriate rotation of the ureteroscope to prevent trapping of the stone in the mucosa. If this occurs, the stone is mobilized by gently nosing it with the ureteroscope and slightly turning it until it can finally be delivered through the orifice. The entire process of extraction is performed under visual control, with good irrigation. If the stone becomes impacted and starts telescoping the ureteral wall, extraction is stopped at once. The basket is loosened, the stone nosed back with the instrument and trapped in the basket in a more favourable position. If a trapped stone is forcefully pulled through the ureter, severe ureteral injury and even avulsion may result. If extraction fails, the stone is disintegrated within the ureter. In case the basket cannot be opened any more, its handle is disassembled and the sheath is removed. The ureteroscope is likewise removed and reinserted along the metal core of the basket for ultrasonic disintegration of the stone to a size that permits safe extraction. Electrohydraulic lithotripsy cannot be utilized for this purpose, because of the electrical hazards when contacting the metal wires.

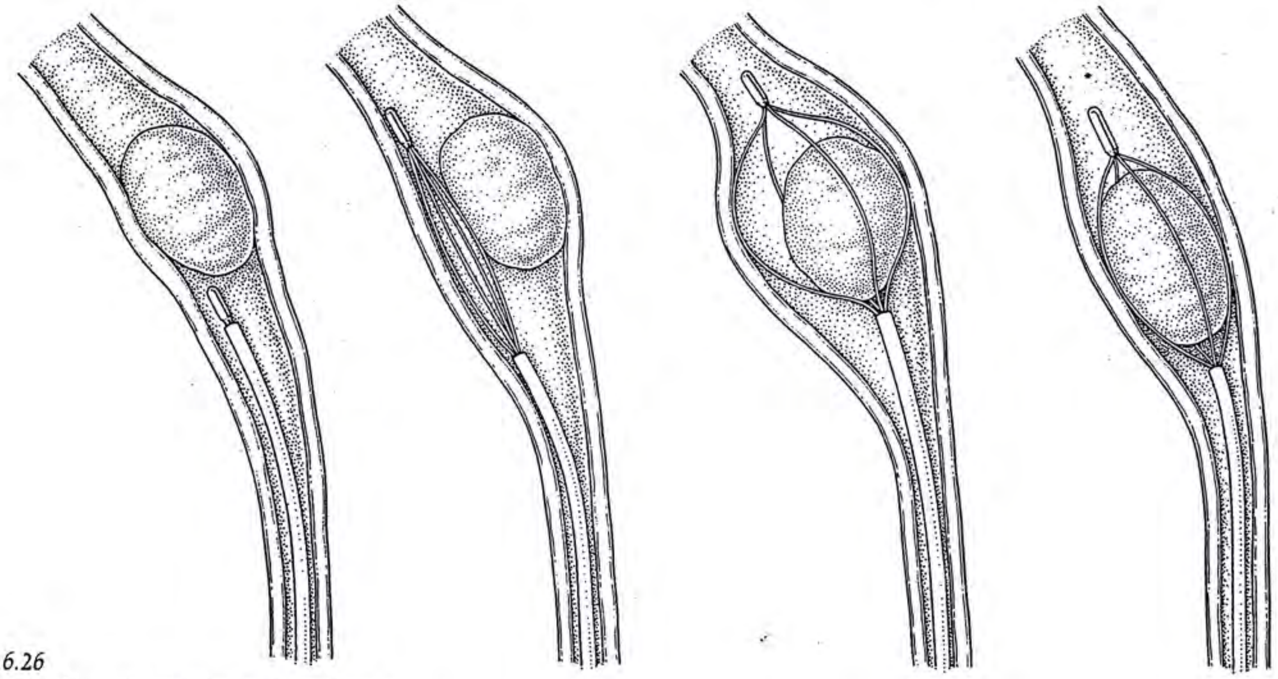


Fig. 6.26
Technique of engaging stone with flat wire basket.

Properly performed, basket extraction of ureteral stones is effective and safe, but violating the rules described above may lead to catastrophe. The most severe complications of ureteroscopy, namely ureteral avulsion, almost always result from improper use of baskets. Endoscopic control of all manoeuvres is essential, but it obviously does not prevent ureteral injury from forced extraction. Proper alignment of the stone within the basket and gentleness at extraction are important, but the relationship between the size of the stone and the diameter of the ureter ultimately decides on the success rate. A definite rule on what size stones can be extracted safely cannot be made, but in our experience stones which are greater than the diameter of the ureteroscope by more than 2–3 millimetres are difficult to extract from a normal ureter, in particular if they are jagged. This corresponds to about 16 F or just under 6 mm. As this only applies for the smallest cross diameter, and half of all ureteral stones are overestimated in size radiographically (Drach 1983), the majority of symptomatic ureteral stones can be extracted. After experiencing ureteral avulsion with stone basketing twice in a series of 236 renoureteral units treated (Stackl & Marberger 1986a) we have become prudent and today make liberal use of ultrasonic or laser disintegration whenever a stone is of borderline size for extraction.

Loop dislodgers have not proven useful for endoscopic stone extraction, as it is difficult to engage the stone securely. The Zeiss loop is a helpful tool, however, when a ureter proves too narrow for stone extraction and methods for intraureteral stone disintegration are not available. The loop is placed as described and left indwelling until it is either expelled together with the stone some days later or ureteroscopy is repeated and the stone can now be extracted because the ureter is dilated.

Intraureteral ultrasonic lithotripsy

Ultrasonic lithotripsy is the most widely used technique for intraureteral stone disintegration today and it is usually our choice. Its physical principles, pitfalls and potential side effects are described in detail in Chapter 5. In short, the steel probe is propelled to oscillating vibrations capable of disintegrating all urinary stones upon contact. Provided the probe is cooled by irrigation with saline at > 20 ml/minute, soft tissue damage other than from the mechanical manipulation itself is negligible (Marberger et al 1985b). Its only major disadvantage lies in the inability to utilize it through flexible instruments, as the energy cannot be led around curves.

Ultrasonic lithotrites for ureteroscopic manipulation are basically variations of renal and vesical lithotrites. With most models the same generator and transducers are used and the equipment only differs from instruments used percutaneously by the type and size of the sonotrode bolted to the transducer. Two types of sonotrodes are available, the solid (wire) rod probes and hollow probes. The former mainly act by their transverse vibration and have the advantage that they are thinner and can be used through a 10.5 F ureteroscope. The latter are available in various diameters from 1.5 mm to 1.9 mm. In general, they require a ureteroscope of at least 12 F tip diameter, but with the short ureteroscopes we have also found 1.5 mm probes used through the 11.5 F ureteroscope effective. Sonotrodes 2.5 mm in diameter are also available, but they have to be worked through the sheath instead of the ureteroscope and hence under fluoroscopic control only (Marberger 1983). The risk of mechanical injury to the ureter is considerably higher and ultrasonic lithotripsy without visual control must be considered obsolete today. The drilling properties of hollow sonotrodes mainly relate to their longitudinal vibrations and correlate with the diameter of the probe and the pressure with which they are pressed against the stone. Both types of sonotrodes seem to be equally effective. As the hollow sonotrodes are connected to an aspirator, stone debris is removed continuously as it is produced. Although the probes tend to become blocked with sand, we find the improved vision a significant advantage and, in general, prefer hollow sonotrodes. Other authors (Fuchs 1988) routinely prefer wire probes and both types should be freely available according to the individual situation.

The surgical technique corresponds to percutaneous ultrasonic lithotripsy. Under full irrigation the probe is tipped against the stone and activated continuously (Fig. 6.27). We have given up bypassing the stone with a balloon catheter and occluding the ureter above the stone to prevent stone migration; if the stone can be dislodged and flushed back into the kidney to be treated by ESWL there, this is always preferable over time-consuming and technically difficult intraureteral disintegration. For the same reason, the stone is also not routinely snared with a basket to keep it in place during disintegration. Most stones subjected to ultrasonic lithotripsy today are so impacted that they can be fragmented in situ. The absence of additional instruments in the working channel improves disintegration. Usually it suffices to break up the stone in several larger fragments, which are then swept out of the ureter with a basket. If some of the smaller fragments escape extraction, this is of no concern. In our experience they are passed without problems after the stent, which we routinely insert for the first two to three postoperative days, is removed. The approach is similar to the Steinstrasse: the lead fragments and larger residuals are fragmented and extracted; the debris is left behind to be passed spontaneously.

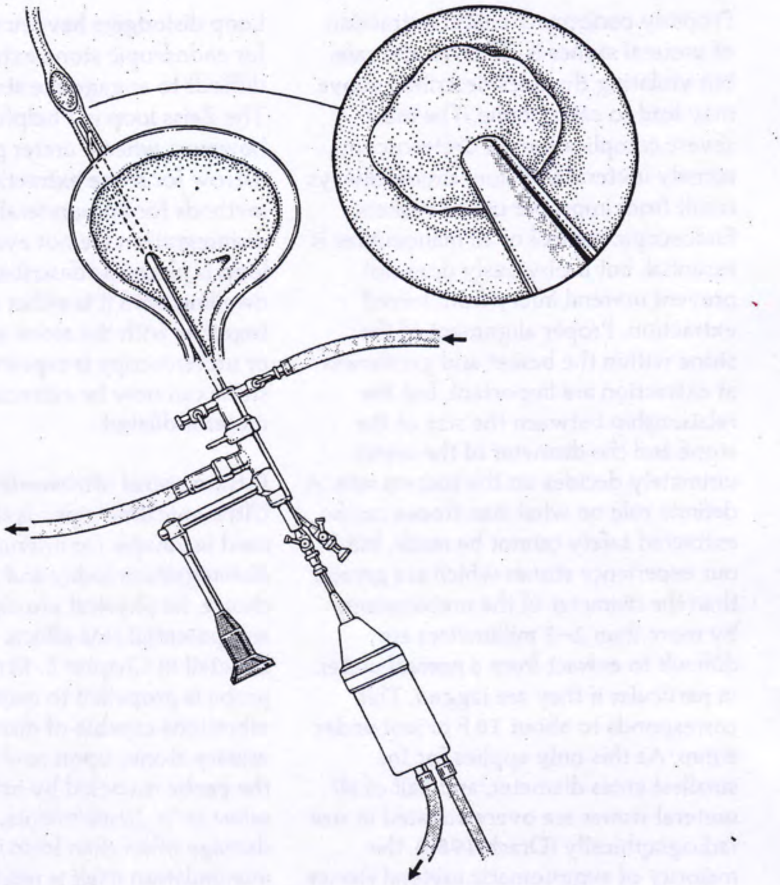


Fig. 6.27
Ultrasonic stone disintegration through the ureteroscope.

Technical problems with ultrasonic lithotripsy arise from the difficulty of manipulating instruments over 50 cm long and only a few millimetres thick in a delicate organ like the ureter (Fig. 6.28). Wherever the sonotrode contacts the ureteroscope of the sheath, energy is lost. This not only results in less energy available at the tip of the probe, but also generates heat at the point of contact (Fig. 6.29). As a result, thermic damage may occur at this point and even breaking of the sonotrode because of fatigue. Bending of the instrument near the eye piece must be avoided for the same reason. As the wire probe bends easiest some manufacturers mount it on a pistol-like grip to prevent this. Bending may also occur along the working length of the instrument within the ureter. The surgeon easily detects this because the round field of vision is reduced as the rod-lens system is brought out of focus with bending. The sonotrode should only be activated when its tip is clearly visible and this usually requires good irrigation. Energy transformation to heat is largest when the sonotrode is activated without tipping the stone (Flachenegger 1988). The probe should therefore only be activated when in contact with the stone, and in bursts of about 30 seconds rather than continuously (Bichler et al 1984).

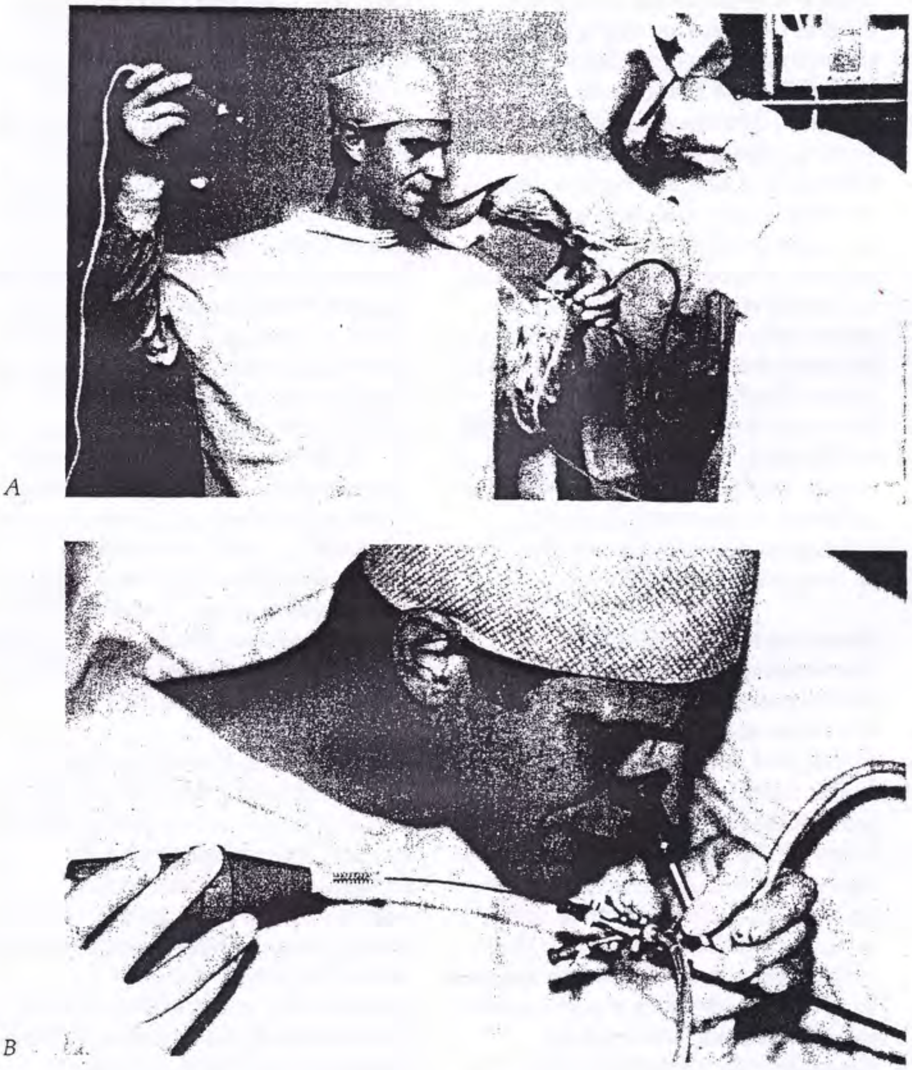


Fig. 6.28

(*A* and *B*) Technical difficulties in handling the ultra-thin sonotrodes, which bend without the surgeon noticing this.

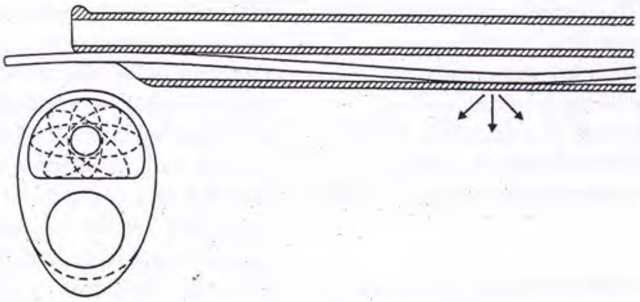


Fig. 6.29

Contact between sonotrode and ureteroscope results in heat development at this point and loss of energy at the tip.

Clinical experience has shown that thermal problems are negligible. More common is mechanical injury from inadvertent use of the probe. It correlates directly with the time needed for stone disintegration, the stone's hardness and size and the difficulty in reaching it. Even full perforation with the probe usually remains without sequelae if recognized and treated with an internal stent for some days postoperatively; usually the procedure can be completed as planned in spite of this mishap (Stackl & Marberger 1985b). The use of the short ureteroscope, with less bending, better irrigation and simpler handling of the instrument, has facilitated intraureteral ultrasonic disintegration decisively (see also Ch. 5, on antegrade ureteroscopy).

Electrohydraulic disintegration

Electrohydraulic lithotripsy is the most effective method of direct contact lithotripsy and it is used extensively to disintegrate renal (see Ch. 5) and vesical stones. Moreover, the electrode used to produce the spark-gap discharges that fragment the stone is flexible, so that it can be used through flexible instruments. Early attempts to contact ureteral stones and disintegrate them under fluoroscopic control only resulted in an unacceptable rate of perforations and strictures and were rapidly abandoned (Reuter & Kern 1973). The reason for this was the obvious soft tissue damage caused by high pressures and heat within a 5 mm zone surrounding the tip of the electrode (Raney 1978, Purohit et al 1980). With the development of ureteroscopes with adequate irrigation systems and spacious working ports, as well as electrodes down to a diameter of 1.8 F, interest in electrohydraulic ureterolithotripsy was revived (Green & Lytton 1985).

The keys to safety are full visual control of the entire process and keeping the tip of the electrode at least 5 mm away from any vulnerable structure during discharge. The safest way to achieve this is by using a 13.5 F ureteroscope with an integrated continuous flow irrigation system. The major advantage over ultrasonic lithotripsy—the thin, yet highly effective electrode—is not utilized with this instrument. Green & Lytton (1985) therefore prefer a 9.5 F rigid ureteroscope with a 3.5 F working channel. With adequate irrigation the 1.8–3 F electrode is tipped against the stone and advanced at least 5 mm away from the end of the ureteroscope to avoid cracking the lens. With the 'single-shot-technique' the discharges are started at low voltage. Depending on the effect observed, the voltage may gradually be raised. Fragments are removed with baskets or forceps, but small debris may just as well be left to be passed spontaneously. An indwelling ureteral stent is routinely inserted for at least 24 hours postoperatively.

Green & Lytton (1985) reported successful disintegration of ureteral stones in 32 out of 36 patients, with an acceptable complication rate. The technique is not without pitfalls, however. The thin electrodes' need for a lower voltage reduces efficacy, and hard stones like calcium oxalate monohydrate or uric acid stones may prove resistant. Furthermore, the small diameter of the probe of necessity reduces the layer of insulation, so that the probes are worn down rapidly and must be replaced or refurbished (see Ch. 5) repeatedly. The technique is difficult to employ with impacted stones, in particular if an oedematous mucosa impairs vision and distensibility of the ureter. If an impacted stone is disintegrated directly adjacent to the ureteral wall, fragments may be sprayed blast-like into the ureteral wall (Webb & Fitzpatrick 1985b). In general, less traumatic and technically simpler ultrasonic lithotripsy is therefore preferred within the ureter. An electrohydraulic generator adjustable to all sizes of electrodes is usually available at stone centres and the additional procurement of some thin electrodes causes little extra expense. Occasionally, smooth stones in large ureters are difficult to corner with ultrasonic lithotrites and electrohydraulic lithotripsy is then simpler.

Laser lithotripsy

The use of athermic lasers (see Ch. 5) for treating ureteral stones is attractive, because the energy can be delivered via thin quartz fibres and because laser energy only has an effect where it is absorbed—hence, potentially only on the stone and not the surrounding soft tissue (Watson et al 1988b). Laser lithotripsy can be utilized through very thin and even flexible endoscopes and, at least theoretically, by advancing the fibres along to the stone under fluoroscopic control. Two systems are undergoing clinical evaluation at the present time.

With the help of localized opto-mechanical coupling, the energy emitted from a Q-switched nano-second-pulsed Nd-YAG laser can be converted to shock waves with an extremely steep shock wave front and a high-pressure amplitude (Hofman & Hartung 1988). The shock wave results from the expansion and attenuation of a localized plasma-filled bubble created as the fluid in the focus of the system vaporizes during the laser-induced breakdown. If this occurs at the interface between the surface of the calculus and the surrounding liquid the stone is fragmented by cavitation processes (Fig. 6.30). With an Nd-YAG laser (K. Storz, Tuttlingen, FRG) of 1064 nm wavelength; 8 ns pulse duration and a single pulse energy of 20–80 mJ, shock waves can be generated with peak pressures of up to 100 mPa. Because of the extremely short discharge time of the pulse and a pulse-repetition rate of 50 Hz, thermal effects are avoided. With the help of a specially designed tube the laser beam is coupled into a 600 μm quartz fibre with a specially formed tip. Using this instrument, Hoffman & Hartung (1988) irradiated various soft tissues, including the ureteral mucosa, with energies exceeding the usual clinical setting. The only biological effects they observed corresponded to mechanical disruption of the most superficial cell layer, with no evidence of thermic damage. In a report on their experience in 27 patients, of whom 23 were treated for ureteral stones with the rigid ureteroscope, laser fragmentation proved effective in all but 3 calcium oxalate monohydrate stones. Optimal results were achieved with an 8 ns pulse duration, 35–50 mJ pulse energy at the fibre tip and a 40–50 Hz repetition rate. With 1000–15 000 pulses administered within 20 seconds to 5 minutes, and an average operating time of 25 minutes, the stones were disintegrated to sand in 17 patients and fragments amenable to forceps extraction in 7 patients. The 3 failures were subsequently treated by ultrasonic disintegration.

The fragmentation threshold, i.e. the minimum pulse energy required to produce stone fragmentation, depends on the absorption and power density. Absorption is poor but for very dark stones in the 1064 nm range Nd-YAG lasers and it is considerably higher at shorter wavelengths in the green to ultraviolet range. Power density is higher the shorter the pulse duration is and the narrower the transmitting fibre. Experimental evaluation of these parameters and their effects on stones respective to soft tissues led to the development of a flash-lamp excited dye laser (Candela, Wayland, Ma, USA) tuned at 504 nm with a pulse duration of 1.0 microsecond, which is transmitted through 200–320 μm fibres at a pulse frequency of 1–20 Hz (Watson et al 1988 a,b). The 320 μm fibre permits a maximum energy output at its tip of about 120 mJ. The fibres are extremely flexible and can be advanced to the stone either through thin ureteral catheters brought through the working port of a standard ureteroscope, or through flexible instruments. Alternatively, a modified flat-wire basket (Van-Tec, Spencer, In, USA) with an axial lumen is available for this purpose; the stone is held in place by the basket and the fibres are advanced through the central lumen. Purpose-built semirigid 6.5–7.0 F ureteroscopes (see Figs 6.12, 6.13) have recently become available, that incorporate principles of rigid and flexible ureteroscopes. Because of their thin outer diameter the invasiveness of ureteroscopy is significantly reduced, yet the laser fibres can be advanced to the stone under full vision.

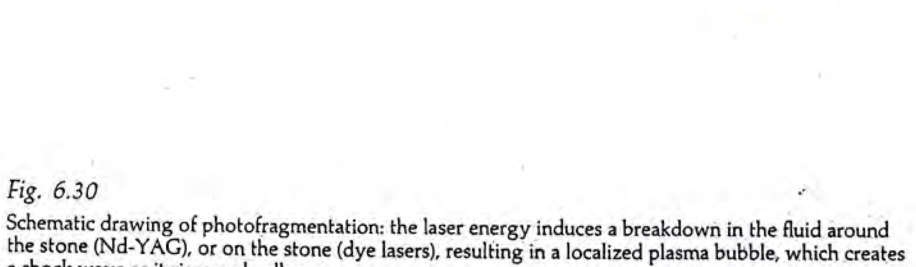


Fig. 6.30

Schematic drawing of photofragmentation: the laser energy induces a breakdown in the fluid around the stone (Nd-YAG), or on the stone (dye lasers), resulting in a localized plasma bubble, which creates a shock wave as it rises and collapses.

The silicone-coated quartz fibres must have a flat, smooth tip. This is achieved with simple cleaving with a diamond-tipped pencil, if necessary during the procedure. It is quite resistant to damage and can therefore be tipped against the stone for optimal results. Fragmentation is started at a low power setting of around 30 mJ and at about 5–10 Hz; the power setting is increased if the stone shows no effect after 100–200 impulses. The stones are disintegrated to fragments small enough to either be removed with a six-wire basket or such that they can be expected to be passed spontaneously (Fig. 6.31). The commercially available unit (Candela, Wayland, Ma, USA) has in the meantime been evaluated clinically at various centres (Coptcoat et al 1988, Dretler 1988, Segura & Patterson 1988). In 2–6.3% the stones could not be disintegrated, in part because of equipment failure. Where ureteroscopy was used, the overall success rate varied from 84–89%, which must be considered a high success rate in view of the negative selection of these patients who were usually unsuitable for ESWL and/or standard ureteroscopy and ultrasonic disintegration. The major problems occurred with retrograde displacement of the stone upwards as it was disintegrated, requiring secondary ESWL. Severe complications resulting from laser irradiation were not observed. Coptcoat et al (1988) also attempted 'blind' lasertripsy by advancing the fibres through a ureteral catheter under fluoroscopic control only. They observed no side effects, but the success rate was only 23%.

The major drawback of laser lithotripsy lies with its complexity. Apart from the high equipment cost, which may reach a fourth of the price of an extracorporeal shock wave lithotriptor, it requires complicated maintenance and is prone to failure. Q-switched Nd-YAG lasers appear to fragment stones faster, but the tips of the fibres used are very sensitive and cannot be refurbished, so that they have to be replaced frequently at extreme cost. These problems are avoided with the pulsed dye laser, but lithotripsy may be quite time consuming, with procedural time occasionally exceeding one hour. The merits of lasertripsy are further balanced by the fact that, in most situations, ureteral calculi can be removed by ultrasonic lithotripsy at considerably less expenditure. Energy transmission via thin and flexible fibres remains a decisive advantage, however, and the present technical shortcomings will certainly be overcome in the near future. In our hands laser lithotripsy with ultra thin semirigid ureteroscopes already is the treatment of choice for stones impacted in the intramural ureter, or in narrow segments not amenable to ultrasonic lithotripsy, and for dissolution of a Steinstrasse.

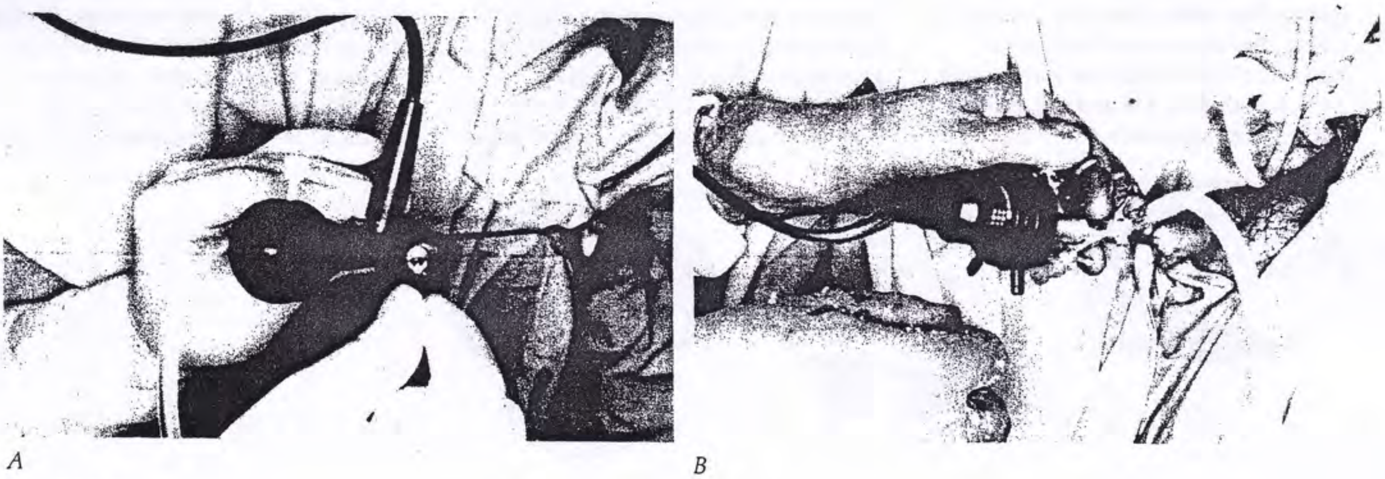

A *B*

Fig. 6.31
Laser light may damage the eye with direct vision endoscopy, unless (*A*) protective filters are used; (*B*) this is unnecessary with video endoscopy.

FLEXIBLE URETEROPYELOSCOPY

Although ureteroscopy started with flexible instruments (Marshall 1964, Takayasu et al 1970) rigid endoscopes are the workhorses in the field. The reasons for this are multifold. Flexible endoscopes in general have a larger external diameter in spite of smaller working and irrigation ports and the ratio deteriorates further if a mechanism for active deflection of the instrument is integrated. Flexible instruments are difficult to handle and require specific training, whereas every urologist is familiar with the handling of rigid endoscopes. Although two to four times as costly, flexible instruments have a considerably shorter lifetime and their vulnerability to damage increases rapidly the thinner they are. Finally, many stone situations where flexible endoscopy appeared attractive years ago are treated with ESWL or percutaneous surgery today. On the other hand, experience with rigid ureteroscopy has taught the urologist that the ureter tolerates ureteral dilatation to at least 15 F without significant damage. Ongoing technical development in the quality and size of fibre optical bundles permitted the construction of flexible instruments with larger instrumentation and irrigation channels and improved accessories, in particular for electrohydraulic and laser lithotripsy. Flexibility has decisive advantages in certain clinical situations and hence a place in the treatment of urinary stones.

Although laser lithotripsy may change the situation, at the present time a flexible ureteropyeloscope suitable for treating ureteral calculi should have a working channel of at least 3.5 F; smaller channels are unsuitable for instrumentation and an instrument of this type serves diagnostic purposes only. Deflection of the instrument can be achieved by passive or active means, depending on whether the ureteroscope merely follows the lumen of the ureter or a guidewire, or whether this is achieved through an active mechanism integrated in the instrument. The latter feature has a significant impact on the diameter of the instrument and its price. Active ureteroscopes (Fig. 6.32) have a diameter 2–4 F larger than passive instruments and are more costly. Their higher rigidity renders them simpler to manipulate and about 85% of the entire collecting system can be reached (Bagley 1987). A high degree of deflectibility is, however, only needed within the kidney and mainly for diagnostic purposes. Passively

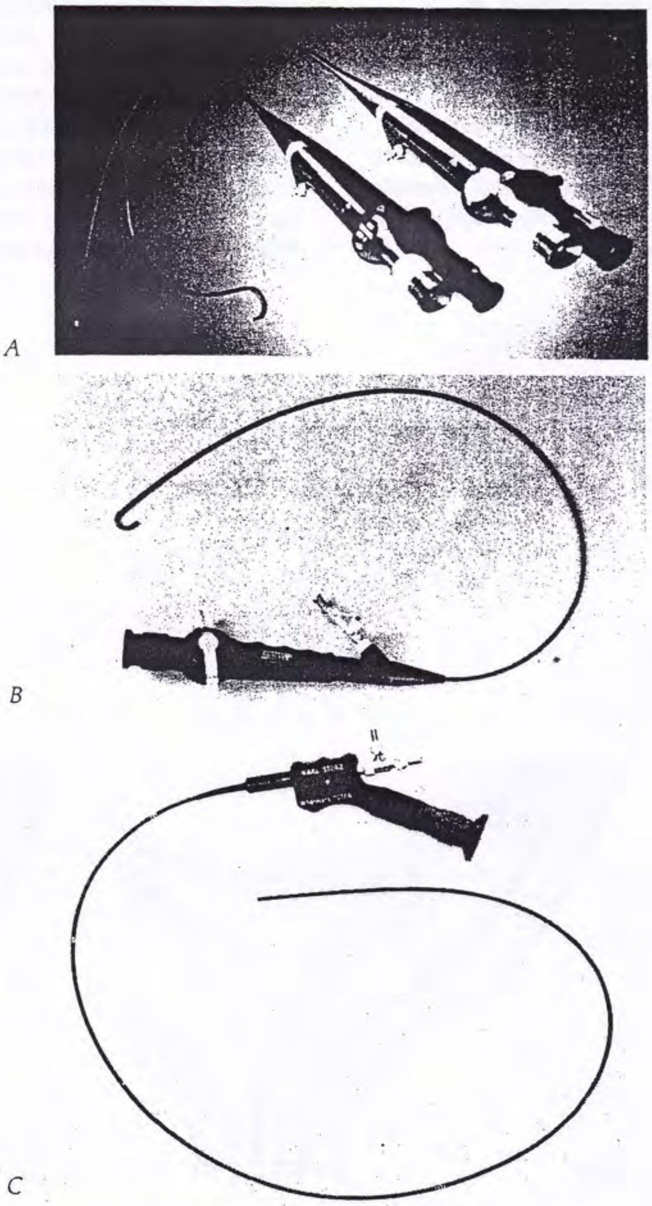


Fig. 6.32

Flexible ureteroscopes: (*A*) active 9.8 F with 160° deflection and 9.8 F working channel (ACMI-Circon); (*B*) 9.5 F active with 150° deflection and 3.3 F working channel (Wolf); (*C*) 7.5 F passive with 3 F working channel (Storz).

deflecting instruments may be just as effective within the ureter, once they have passed the ureterovesical orifice. Moreover, they are somewhat more rugged than active deflectible versions and can be passed through the working channels of rigid instruments like ureteral catheters. As they are also considerably cheaper, they appear suitable as the first choice of instruments. The more expensive and fragile active deflectible instruments are reserved for the situations where the former fail (Bagley 1987, Aso et al 1988). The instruments are subject to rapid technical changes and a complete overview is beyond the scope of this presentation.

Before the flexible ureteropyeloscope is used in vivo, the surgeon must be thoroughly familiar with handling it, especially if it is of the active deflectable type. All accessory instruments should have been tried with the instrument to avoid surprise situations during surgery. The instruments are very fragile and they must therefore be handled with the greatest care to avoid damaging them. For this reason they are cleaned immediately after use on a table free of any other instruments, stored and sterilized in purpose-built containers and kept in these on a separate side table at surgery until they are used. The instruments are not only easily damaged by kinking, but also by forcefully advancing rigid objects down the working ports to clear clogged channels.

Unless the ureter and ureteral orifice are abnormally wide, flexible ureteroscopes cannot usually be inserted directly into the orifice. Because of their low rigidity they tend to buckle within the bladder. The ureteral orifice therefore routinely has to be dilated. It is more difficult to insert flexible instruments than rigid ureteroscopes. We therefore routinely dilate the orifice with a 5 mm balloon angioplasty catheter, which is inserted over a guidewire. Most larger instruments have a working channel appropriate to accept a guidewire. If the ureteral orifice appears rather wide after balloon dilatation, the cystoscope is removed and the guidewire stays in place. It is threaded through the channel of the ureteroscope and the instrument is then inserted under direct vision, following the guidewire. As the orifice is reached, the instrument is turned 180° to elevate the medial lip of the orifice with the guidewire which lies in the eccentric working channel (Fig. 6.33A) (Bagley 1988).

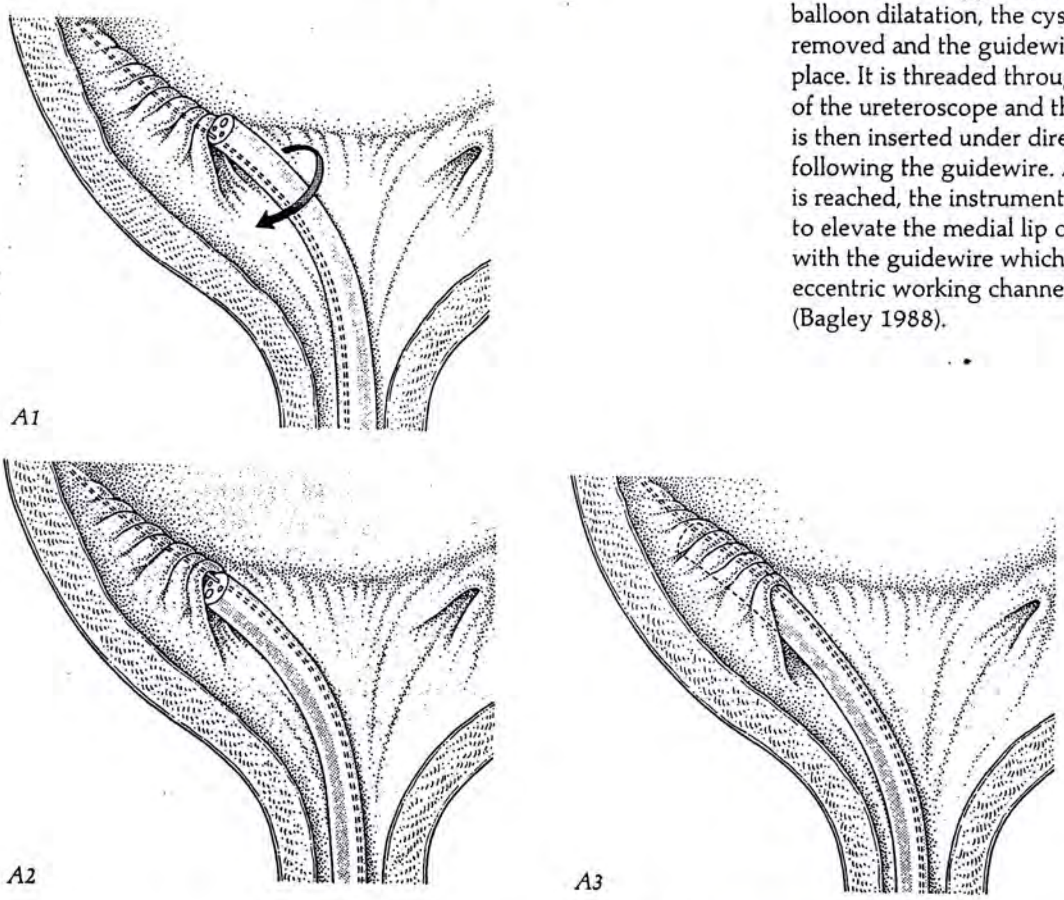


Fig. 6.33

Inserting the flexible ureteroscope into the ureter: (*A* 1–3) elevation of the medial lip of the orifice with a guidewire and turning the instrument 180°; (*B*) through the sheath of a short 12.5 F ureteroscope which is first inserted under vision; (*C* 1, 2) through a peel-away guide tube advanced over tapered dilators.

Thin ureteroscopes can occasionally be inserted through the working port of a 24 F cystoscope, leaving the cystoscope sheath in place during intraureteral manipulation. We usually prefer to insert the short, 12.5 F ureteroscope along the guidewire instead. Using the same 180° twisting movement to pass through the intramural portion, it is advanced to just below the curved portion of the intrapelvic ureter. Leaving the sheath and guidewire in place, the rigid endoscope is removed and the distal end of the sheath sealed with a rubber lock. The sheath now serves as a guide tube for the flexible nephroscope (Fig. 6.33B); if the instrument has a channel suitable for accepting a guidewire it is advanced over the guidewire, otherwise the guidewire is removed. It should not be jammed down alongside the guidewire, as this may injure the instrument.

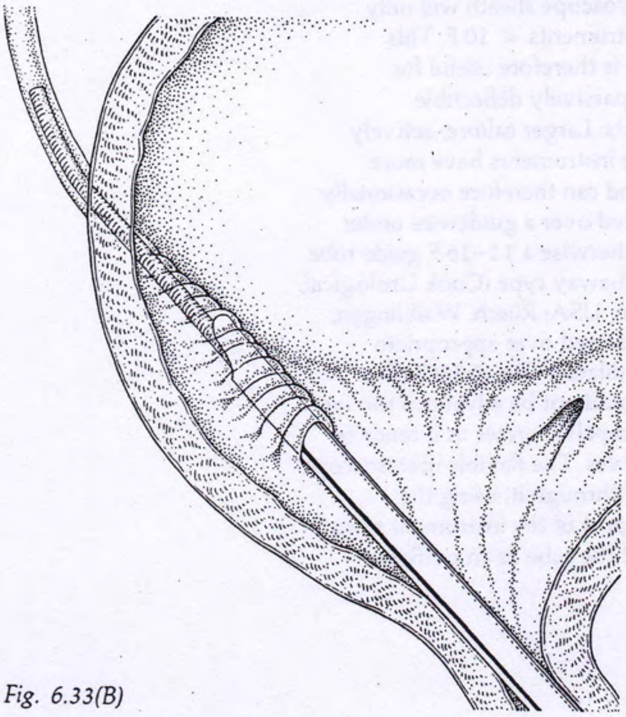


Fig. 6.33(B)

The ureteroscope sheath will only accept instruments < 10 F. This technique is therefore useful for inserting passively deflectible instruments. Larger calibre, actively deflectible instruments have more rigidity and can therefore occasionally be advanced over a guidewire under vision. Otherwise a 12–16 F guide tube of the peel-away type (Cook Urological, Spencer, In, USA; Rüsch, Waiblingen, FRG) is inserted over appropriate telescope dilators (Fig. 6.33C). The sheath should not be advanced too far up the intrapelvic ureter as it tends to kink at curves. The flexible ureteroscope is inserted through it, using the irrigation port of the instrument as an inflow and the tube as an outflow channel.

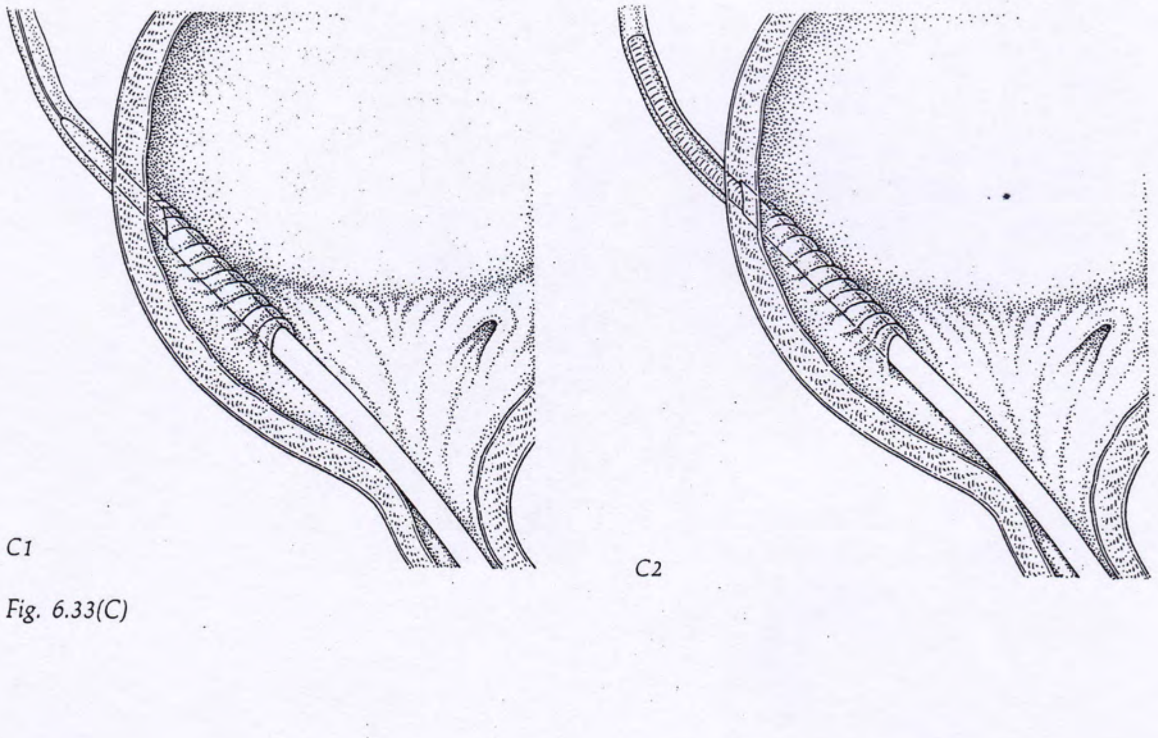

C1
C2

Fig. 6.33(C)

As the flexible ureteroscope is advanced up the ureter under vision, it is important to keep any guide tube or sheath used aligned with the direction of the ureter to avoid displacement and kinking of the endoscope. Good irrigation is most important and it may be helpful to pressurize the bag of saline with a blood pressure cuff. The instrument should be advanced along the visible lumen of the ureter and, if the endoscope has an active deflection mechanism, the tip should be turned to follow the ureter. It is definitely helpful to know the precise course of the ureter and fluoroscopic control is mandatory. Diluted contrast dye is injected through the instrument as needed. The endoscope may also be connected directly to a television camera and guided by the image on the television screen. If the television monitor is positioned directly under the fluoroscopy screen, the surgeon does not need to turn his head when he changes from endoscopy to fluoroscopy (Fig. 6.34).

If the instrument cannot be advanced because of tortuosity of the ureter or narrow segments, the techniques described on page 143 can also be applied. The irrigation properties of flexible endoscopes are usually poorer than those of rigid endoscopes and if haematuria occurs vision usually rapidly deteriorates. In this situation it is advisable to wait for several minutes until bleeding stops and the clots are flushed from the collecting system.

Just as with rigid ureteropyeloscopy, smaller stones can be extracted with 3 F flat wire baskets (Microvasive, Spencer, In, USA) or three-prong flexible grasping forceps (Cook Urological, Spencer, In, USA). The instruments can be advanced through the working port of 8.5 F or 9 F flexible non-deflectible ureteroscopes that can be inserted into the ureter directly through a 24 F cystoscope over a guidewire (Preminger & Kennedy 1987). The technique is simple and avoids extensive dilatation of the intramural ureter. The flexible instrument may be damaged by kinking against the cystoscope, but the passive instruments are smoother and somewhat sturdier. More intricate stones requiring electrohydraulic or laser disintegration can usually only be managed with active deflectible instruments, as the techniques require precise positioning of the electrode or laser fibre (Begun et al 1988, Dretler et al 1987). Although effective, the complexity of procedures of this type limits the practical use at the present time to situations where rigid or semi-rigid ureteroscopy fails. The typical scenario of this kind is an impacted stone in a rigid ureter displaced by previous surgery; frequently the antegrade percutaneous approach may be preferable (see Ch. 5) to the retrograde access.

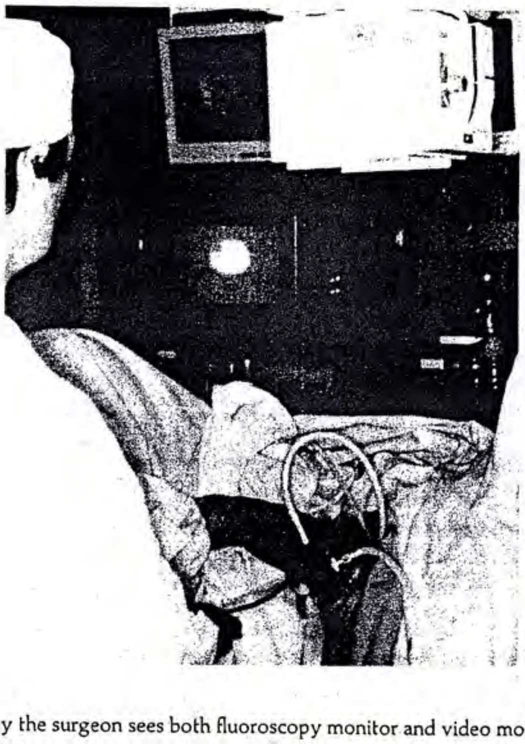


Fig. 6.34

With video endoscopy the surgeon sees both fluoroscopy monitor and video monitor continuously.

PERIOPERATIVE CARE

If the stone was completely removed and the urinary tract remained intact, major problems are not to be expected after ureteroscopy. Because of oedema at the ureterovesical junction and the former stone bed, transient obstruction may occur, in particular as clots are passed. This frequently results in renal colic, pain, or at least discomfort after the procedure and may extend hospitalization. We, therefore, routinely insert a self-retaining ureteral stent after ureteroscopy. In our experience this virtually abolishes the minor problems from transient obstruction and any complications from unnoticed perforation or injury of the ureter.

As we usually do not use a 'safety guidewire' because of its interference with intraureteral manipulation, the stent is routinely inserted through the sheath of the ureteroscope. If the stone was extracted with a basket, the endoscope is reintroduced into the distal ureter with this standard technique. The endoscope is then removed from the sheath and a standard 7 F self-retaining ureteral stent with closed tip is advanced up into the renal collecting system under fluoroscopic control. It is already on its guidewire and backloaded by an extra-long pusher (Fig. 6.35). As soon as the renal tip is in its correct position the sheath is gradually withdrawn, holding the stent with the still-taut guidewire in place.

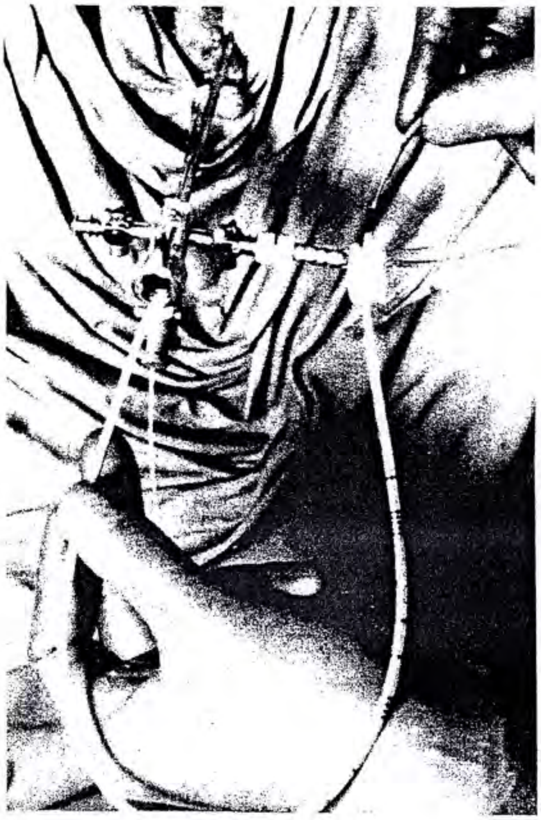


Fig. 6.35

Insertion of indwelling stent directly through the 11.5 F ureteroscope sheath, after the ureter above the stone bed is reached under vision; if the stent cannot be passed, a hydrogel-guidewire is inserted through the ureteroscope under vision, the endoscope removed and an open-ended stent railroaded to the kidney.

The guidewire and pusher are removed after the endoscope sheath. The correct position of the stent is again controlled fluoroscopically, but we also routinely check the vesical end of the stent for its correct position endoscopically.

If the stent cannot be advanced over the former stone bed or a kink of the ureter, the ureteroscope is advanced under vision up to this level and stent insertion is reattempted. When the stent cannot be guided over a ureteral kink, it occasionally suffices to apply traction to the ureter by slightly pulling the sheath and thus straightening the ureter. With severe perforation, manipulation under fluoroscopic control alone should be avoided, lest damage be increased. In this situation the endoscope is again advanced to the lesion, which is by-passed with a 5 F open-ended ureteral catheter under vision. Leaving the sheath in place, the catheter is used to insert a guidewire for an open-ended stent. In this situation, 7 F or 4.5–5 F stents placed over 0.025 guidewires usually have to be resorted to. The stents should have a low elongation capacity, rather high rigidity and a low dynamic coefficient of friction. Polyurethane stents are our usual choice, provided their pusher is at least 50 cm long. Hydrogel-coated stents (C-flex/hydromere, Microvasive, Spencer, In, USA) and guidewires (Lubriglide, Microvasive, Spencer, In, USA) may even be better. 4.5 F stents can also be inserted under vision through the working port of a 12.5 F ureteroscope. With the long endoscope version, they have a high tendency to be impacted within the working channel, so that they are withdrawn inadvertently as the instrument is removed; the technique therefore usually only works with short ureteroscopes. If stenting fails with significant perforation or obstruction, we routinely insert a thin percutaneous nephrostomy to drain the kidney in the same session. Most perforations seal spontaneously, provided the kidney is drained properly.

In general, the patient can be discharged from the hospital after 24 hours. Antimicrobial agents are not routinely administered if the urine was sterile. Only when a stone is removed from an extremely obstructed system and this involves retrograde manipulation, is a single-shot dose of 120 mg i.v. gentamycin given at the time of instrumentation. Urinary infection is, of course, treated aggressively with appropriate antibiotics.

A standard plain film is obtained before the patient is discharged to detect any stent displacement or residual stones. Obstruction of the kidney is ruled out by ultrasonography. In uncomplicated cases the stent is removed on an outpatient basis after 1–3 days. Stents with their vesical end looped through a suture, which is led out through the urethra, can be removed without cystoscopy. The suture tends to irritate the urethra and to catch in clothing, so that we only use this technique if the stent is to remain in place for less than 48 hours. Otherwise it is more comfortable for the patient to have the stent removed in topical anaesthesia with the flexible cystoscope, or a 14 F minicystoscope on an outpatient basis. Ultrasonography of the kidney is again performed 24 hours after stent removal to rule out obstruction. By this time the results of the stone analysis and the metabolic work-up are available for the final consultation.

Intra- and postoperative complications are dealt with in a separate chapter.

RESULTS

The success rate of ureteroscopic stone manipulation depends on patient selection, but the experience of the surgeon and the available equipment also have a decisive impact. Although initially we treated rather simple stones in the distal ureter only by ureteroscopy, the failure rate came close to 50%; with increasing experience and the availability of second and third generation instruments the technique was expanded to practically all ureteral stones and finally reached a success rate well over 95% (Fig. 6.36). From the equipment side, the final step for expanding ureteroscopic stone manipulation to the entire spectrum of ureteral stones came with the development of ultrasonic uretero-lithotripsy under vision. Virtually all stones were now treated endoscopically, yet the perforation rate dropped to less than 9% (Marberger 1984, Stackl & Marberger 1986a,b).

If only the retrograde approach is used, stones in the distal third are obviously easier to treat than stones in the mid and proximal third of the ureter, with success rates varying from 84–96%, 67–80% and 22–60% for these sites (Huffman & Bagley 1988b). It is considerably simpler to treat stones in the proximal ureter in the antegrade direction, in particular if the ureter is dilated and the antegrade stones require intraureteral disintegration (Marberger 1984, Miller et al 1985, see Ch. 5). After experiencing inadvertent dislocation of stones into the kidney during retrograde ureteroscopy and in view of the low morbidity of percutaneous extraction of these small stones, another policy was directed at flushing stones in the proximal half of the ureter back into the kidney and removing them from there (Clayman et al 1984, Kellett et al 1985, Marberger 1984).

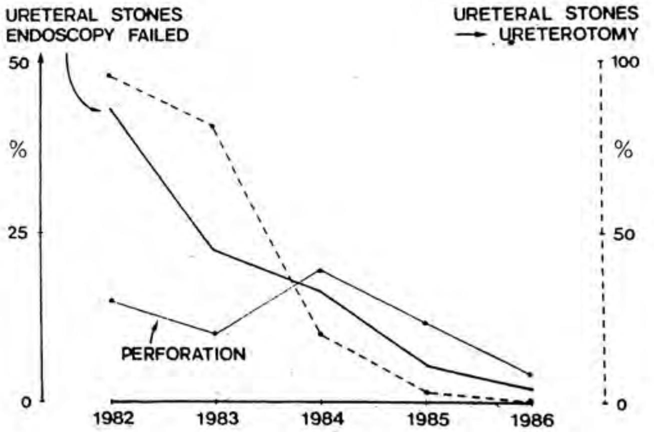


Fig. 6.36

Learning curve and impact of improved equipment on results of ureteroscope (Rudolfstiftung Vienna; 629 ureteroscopic procedures, 1982–1986).

By utilizing the entire spectrum of possibilities, the success rate of endoscopic stone removal was increased to around 90% regardless of the position of the stone. Free availability of ESWL and its increased utilization for treating ureteral stones either in situ or after manipulating them back into the kidney (see Ch. 3) have reduced the need for ureteroscopy significantly. In our institution ESWL is the first choice for treating ureteral stones today (Fig. 6.37). Ureteroscopy is reserved for stones that cannot be localized or flushed back into the kidney, or if ESWL fails. Ureteroscopy is most successful and simplest in the distal ureter, in particular for stones that can be extracted, but in spite of the attraction of immediate stone removal and success rates > 95% it is more invasive (El-Faquih et al 1988) and results in about 2% serious complications (Stackl & Marberger 1986a). This trend is increased even more by the elimination of the need for anaesthesia with second generation lithotriptors. Nevertheless, ureteroscopy remains an essential alternative where ESWL fails.

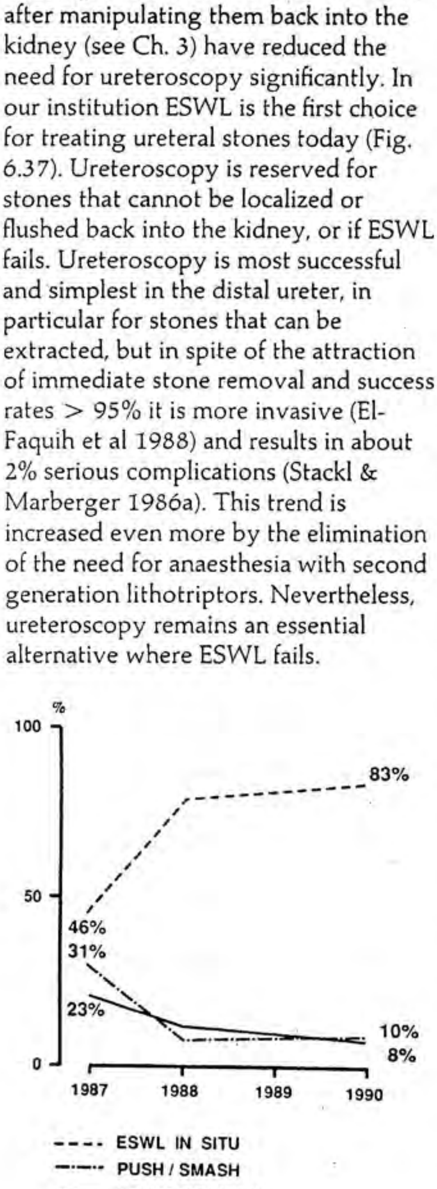


Fig. 6.37

Choice of primary treatment of ureteric stones with availability of second generation lithotriptors and simplified ESWL in situ of ureteral stones (Rudolfstiftung Vienna, 1452 renoureteral units).

Moreover, the treatment of Steinstrasse has become a new challenge and further development of flexible endoscopy techniques and lasertripsy may also result in a change of indications again.

COMPLICATIONS AND THEIR MANAGEMENT

The main reason for the rapid acceptance of ureteroscopy for removing ureteral stones came from its significantly lower morbidity as compared to conventional methods. The advantage of avoiding 'cutting for stone' with its inherent pain and immobilization is obvious, even when non-muscle-splitting incisions are used. In a retrospective review of over 1000 patients undergoing ureterolithotomy or conventional transurethral stone manipulation at the Mayo Clinic in a 15-year period, Furlow & Bucchiere (1976) found 10% morbidity in patients having successful stone manipulation, 18% morbidity in those undergoing ureterolithotomy and 25% morbidity if open surgery was preceded by an unsuccessful manipulation. Complications varied from recurrent ureteral colic and delayed wound healing to prolonged urinary extravasation and death. Amar et al (1981) report a 4–5% stricture rate after ureterolithotomy. Once the learning curve is overcome (see Fig. 6.36), the morbidity of stone manipulation under vision is certainly lower. Neverthelless, about 15% of the patients undergo minor complications that require some alteration of the original treatment planned and about 2% suffer serious complications requiring specific surgical intervention.

Most of the minor complications can be avoided or managed as they come up, without adding to the morbidity of the procedure, by following the guidelines outlined previously. Serious complications result only if the following basic rules are violated:

1. Ureteroscopy only in general or high epidural anaesthesia.
2. Free availability of fluoroscopy during entire procedure.
3. Precise preoperative patient evaluation, in particular in respect to stone localization and ureteral anatomy and pathology.
4. Appropriate antimicrobial treatment of urinary infection; with severe infection and obstruction, relief of obstruction by percutaneous nephrostomy 2–3 days prior to ureteroscopy.
5. Dilatation of the intramural ureter under endoscopic and fluoroscopic control, always over guidewires and not > 15 F.
6. Endoscopic manipulation under adequate vision only.
7. Retrograde opacification of ureter in case of problems.
8. Basket extraction under vision only.
9. Gentle basket extraction only, liberal use of ultrasonic or laser lithotripsy to reduce stone size.
10. Ultrasonic lithotripsy in bursts of 30 seconds only, with good irrigation.
11. Routine insertion of stents after stone removal.
12. Never be time squeezed.
13. NEVER FORCE IT!
14. If unmanageable problems occur, the procedure is discontinued and the kidney drained with a stent or percutaneous nephrostomy; usually a second attempt at a later time is successful.

Stone cannot be reached

A ureteral stricture or a large median lobe of the prostate may render access to the ureteral orifice difficult. A urethrotomy may be combined with ureteroscopy, but major bladder neck surgery should not be performed at the same time, because of the impaired vision with haematuria. Occasionally the ureteral orifice can only be visualized with the flexible cystoscope. Ureteroscopy should only be attempted in this situation if the ureteral orifice appears wide and accessible to rigid instruments, once its location is defined. If any doubt exists as to the precise location of the orifice in a trabeculated or oedematous bladder, the issue should be cleared by administering indigo carmine intravenously.

Ureteroscopy is always commenced by passing a ureteral catheter or a guidewire up the ureter and into the renal pelvis. If this is not achieved with the techniques detailed on page 135, endoscopy under vision is attempted using the smallest calibre ureteroscope available. Using the technique described on page 137, it can usually be inserted at least into the intramural segment of the ureter and it may then be possible to advance a guidewire under vision. Unguided metal dilators should never be used. If this technique fails, the ureter can still be intubated with a guidewire in the antegrade direction via a percutaneous nephrostomy. In general, however, another approach at removing the ureteral stone will be more appropriate.

In well over 60% of all ureters a short 11.5 F ureteroscope can be inserted without formal dilatation of the intramural ureter, using the technique described on page 135. The instrument is always advanced over a guidewire or an open-end ureteral catheter. If this technique fails, ureteral dilatation is performed over the guidewire which is inserted with the help of the ureteral catheter. Should the guidewire be displaced inadvertently during an attempt to pass the orifice with the endoscope, this should never be performed blindly. With forced irrigation the lumen of the ureter usually becomes visible and the guidewire can be reinserted. If this fails, the guidewire is advanced in the antegrade direction via a thin percutaneous nephrostomy. If a guidewire can be advanced down the ureter and into the bladder, it is usually preferable to utilize it to insert a ureteral stent and to continue the procedure some days later.

Occasionally the intramural portion of the ureter is extremely tight. In general, we use intermittent teflon dilators up to 12 F if dilatation is needed. If the 9 or 10 F dilator meets with significant tissue resistance, balloon dilatation is preferable. Alternatively a 7 F internal ureteral stent may be inserted and the procedure is continued in 2–3 days. By this time the ureteral orifice has always dilated to some degree so that the 11.5 F ureteroscope can be passed without dilatation. We feel that this is less traumatic than forced dilatation in one session.

The ureteroscope should only be advanced up the ureter under clear vision. With a 'red-out', all manipulation should be stopped at once. The instrument is retracted for at least 1 cm and irrigation is increased either manually with a 20 ml syringe or with a roller-pump. With the correct technique the ureteral catheter or guidewire being followed is clearly visible and its position in the renal collecting system can be controlled fluoroscopically. If there is any question in this respect, a retrograde ureteropyelogram is obtained. Narrow segments of the ureter may require hydraulic or segmental balloon dilatation. The former technique is very effective for less rigid contractions of the ureter. In general, before resorting to balloon dilatation, we prefer to stage the procedure. A 7 F ureteral stent is inserted into the ureter and the procedure is continued after 2–3 days; the narrow segment can now virtually always be passed. Problems of this type mainly occur at, or above, the pelvic brim. At our institution, ureteroscopy is now mainly restricted to instrumentation to the distal and mid-ureter and the frequency of staged procedures has dropped from 14% to 5%.

Perforation

Perforation of the ureter occurs in approximately 6% to 12%, with even higher rates in ureters fixed by previous surgery, pelvic irradiation (Fig. 6.38) or periureteral pathology (Stackl & Marberger 1986a). Its most obvious immediate risk appears to be urinary extravasation, with the potential of periureteral fibrosis and ureteral stricture. Although Kramolowsky et al (1987) reported stricture formation in about one-third of the patients that suffered perforations, this has not been our experience (Stackl & Marberger 1986) nor that of other authors (Lyon et al 1984, Lytton et al 1987, Schmöller et al 1983). When detected at the time of the intervention and treated by reliable diversion of urine with an internal ureteral stent or a percutaneous nephrostomy, it usually seals within 1–3 days. Basically, every ureterolithotomy represents a 'perforation' and, in spite of frequently prolonged urinary extravasation, the stricture rate is below 5% (Amar et al 1981).

The major risk of perforation lies in rendering intraureteral manipulation more difficult. Because of the leaking irrigation fluid, the ureter tends to collapse and vision is impaired; mucosal tears and haemorrhage may further aggravate this. As the ureter is weakened at the point of injury, it tends to be more susceptible to mechanical force and a minute perforation may rapidly increase to a large tear, again promoting false passage and, ultimately, severe injury of the ureter.

Management of perforation depends on the extent of the lesion and on whether the stone has been removed or not. A minor lesion rather distant to the stone, such as in the intramural ureter with a stone near the pelvic brim, still permits completion of the procedure as planned.

Occasionally, a minor perforation is noted while the instrument is advanced up the ureter, but it can be passed without problems. If stone removal does not require major intraureteral manipulations and the insertion of a stent appears simple, the procedure may then often be completed.

More frequently, the lesion can just be passed with the ureteroscope, but it appears doubtful if a stent placed fluoroscopically would pass. In this situation it is always safer to use the position of the sheath above the lesion to insert a stent to bypass the stone and to terminate the procedure. If a very large impacted stone with an obstructed kidney cannot be bypassed and the perforation is of an extent that precludes major manipulation, it may be advantageous to remove the stone by ureterolithotomy in the same anaesthetic and to stent the ureter at open surgery. On the other hand, if the perforation occurs in the terminal phase of intraureteral stone disintegration and obstruction is more or less removed, we tend to continue with the procedure as planned in spite of some dehiscence. The objective is always to be certain to remove obstruction and provide reliable drainage. If the stone was removed, but a stent cannot be inserted, we routinely insert a percutaneous nephrostomy. After 24 hours an antegrade nephrostomogram is obtained and if it shows no extravasation it is clamped for some hours and finally removed. If extravasation is still noticed after 5 days, antegrade stenting is attempted. Ureteral stents remain in place for 1–4 weeks depending on the extent of ureteral damage. If the stone is still within the ureter, it is prudent to wait for at least 1 week before the procedure is repeated.

Major ureteral injury

Severe ureteral injury may occur in the sequence of perforation, if forceful manipulation is continued. This may happen in the dilatation phase, and guidewire, dilators and the subsequent ureteroscope may follow a false passage. They may parallel the course of the ureter and plain films can even suggest a correct position of the instrument (Lytton et al 1987). If the ureteral lumen and stone are not definitely identified as the ureteroscope is advanced, a retrograde ureteropyelogram has to be obtained at once to

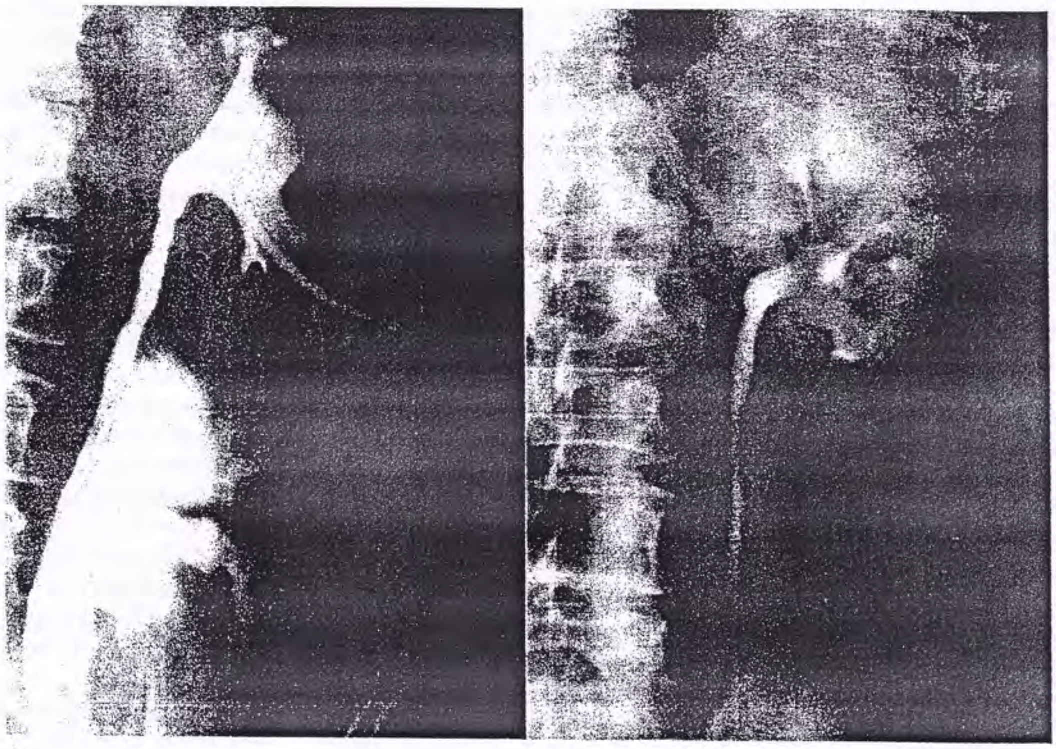


Fig. 6.38

Ureter 'frozen' after pelvic irradiation and surgery: (*A*) perforation during ultrasonic stone disintegration in the mid-ureter; the stone was completely removed, the ureter stented for 6 weeks and, in addition, a nephrostomy placed for 4 days; (*B*) recovery was uneventful and the excretory urogram one year later was normal.

clear the situation. The instrument shearing along the adventitia of the ureter may cause significant damage to the blood supply, but the major damage occurs at the point where the instrument penetrates the ureteral wall.

Another rare but typical mechanism of severe injury may occur when the rigid ureteroscope is advanced through the intramural ureter with force, in particular if the medial lip of the orifice is not lifted up prior to inserting it. Both the delicate intrinsic musculature of the intramural ureter and Waldeyer's sheath may be sheared off as the ureter is telescoped into the retroperitoneum. As the ureter may remain on the tip of the endoscope, the lumen is still visible endoscopically, but in spite of an apparent movement upwards the image stays the same; retraction of the instrument by some centimetres immediately demonstrates circular, complete avulsion of the ureter.

By far the most severe injuries of the ureter occur with inappropriate use of stone baskets (Biester & Gillenwater 1986, Kaufmann 1984, Stackl & Marberger 1986a). They result either from trapping of the ureteral wall or attempts to extract a stone obviously too large for extraction. As undue force is applied, the ureter is completely avulsed. This almost always occurs at the point where it is fixed, i.e. at the ureterovesical junction or where it was fixed by previous surgery and peri-ureteral scarring. Complete avulsion at basket extraction cannot be missed by the surgeon. He feels the tissues 'give' and the ureter may be everted into the bladder. The complication can reliably be avoided if the basket is closed under vision only, taking care not to trap the mucosa, and if extraction is stopped when basket and stone are trapped. Using the techniques described earlier, the stone can usually be nosed back into a wider segment of the ureter and either be realigned or disintegrated there with ultrasonic or laser lithotripsy. In case a basket cannot be opened any more, and the stone cannot be disintegrated, it has to be removed by surgery (Fig. 6.39).

With obvious complete avulsion of the ureter, immediate surgical repair—in general, ureteroneocystostomy—is indicated (see Ch. 8). If a large obstructing stone is still in place and the endoscopic findings and the retrograde ureterogram suggests severe damage, ureterolithotomy, open stenting of the ureter and drainage of the ureter carries least risks. If the injury occurred in the prevesical ureter and the ureter appears discoloured we would consider an immediate ureteral reimplanttation with removal of the damaged segment the safest approach. If the stone was removed or can be managed with another technique like ESWL, we favour a more conservative approach. Internal stents usually cannot be placed in this situation and extended attempts in this direction should be avoided if the injury is not to be augmented. The kidney is drained by a percutaneous nephrostomy placed in the same anaesthetic. What appears to be massive extravasation

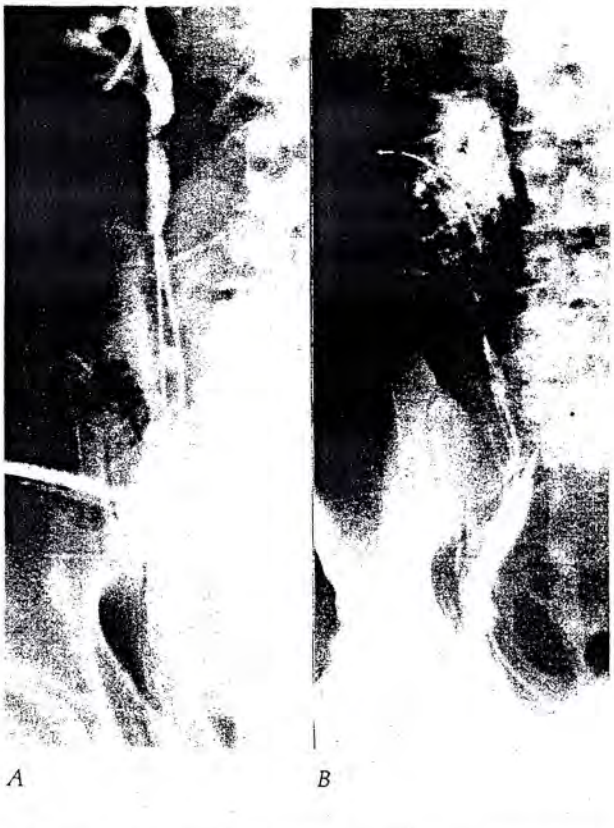

A B

Fig. 6.39

Ureteral stone (9 × 6 mm) after previous pyelo- and distal ureterolithotomy; because of a stricture at the former ureterotomy site the stone was not reached with the ureteroscope, but the ureter perforated. An indwelling stent was inserted and the stone was found to be very mobile in the mid-ureter (*A*). Rather than staging the procedure, immediate removal by antegrade percutaneous extraction was attempted. The stone was successfully engaged, but for this both the indwelling stent and safety guidewire had to be removed. Subsequently, stone and basket became impacted in a segment strictured by the pervious pyelotomy, resulting in perforation at this point also (*B*). As the ureter could not be reintubated again, stone and basket were removed by open surgery.

may normalize rapidly. We, therefore, routinely perform an antegrade nephrostogram after 24 hours. In order to avoid a 'dry anastomosis' (Chang & Marshall 1987) antegrade stenting is attempted as soon as dye-extravasation disappears. Frequently the need for major reconstructive surgery is avoided.

Urinary infection

If the urine was sterile prior to ureteroscopy, the procedure was uneventful and obstruction was relieved, complications from urinary infection are rare. There may be an occasional spike of fever within the first 48 hours, which is usually related to transient obstruction from oedema, a clot, or a stone fragment. It usually normalizes with forced fluids and broad-spectrum oral antibiotics, but ultrasonography of the kidney should always be obtained to rule out severe obstruction. If the collecting system appears dilated and even mild pyrexia persists over more than 24 hours, an excretory urogram should be obtained. Frequently it just shows some slight dilatation of the ureter down to the former stone bed, or to the intramural ureter. This situation usually resolves without further problems. With more significant obstruction and signs of extravasation, the kidney should be drained immediately by inserting a ureteral stent. If this fails, a percutaneous nephrostomy must be placed. Again, unless the ureter was severely damaged, the situation will rapidly normalize without need for further interventions. In our experience, patients that were sterile preoperatively are also sterile after an uncomplicated procedure at late follow-up. In spite of an occasional sterile reflux, cortical scarring does not occur (Stackl & Marberger 1986a, b).

Urinary infection should be treated prior to any endoscopic manipulation. With symptoms of acute renal infection and radiographic or ultrasonographic evidence of significant renal obstruction, we routinely insert a thin nephrostomy tube percutaneously to drain the kidney as an emergency procedure. This can be performed under local anaesthesia with minimal side effects and guarantees reliable drainage of the kidney. The ureteral stone is removed after all acute symptoms have subsided and infection was treated by appropriate antibiotics according to culture identification of the micro-organisms and sensitivity testing. In general, this is achieved within 3 days. With this staged approach the results of endoscopic removal of infected ureteral stones come close to the results achieved with non-infected stones. With the elimination of obstruction, urinary infection is usually eradicated without further problems (Stackl & Marberger 1986).

The only serious complications we experienced from infection occurred when completely obstructed, infected tracts were manipulated. In both cases the patient had had minor symptoms of infection, but the urine was sterile and the ureter was blocked by a prevesical stone. As the ureteral catheter was inserted into the ureter pure pus drained alongside it immediately. In both patients the stones could be removed by very rapid and simple procedures without any technical complications, but both immediately developed endotoxaemia and septic shock, with one patient requiring respiratory assistance for several days. Since this experience we routinely treat patients with a severely obstructed, poorly functioning kidney and mild symptoms of infection as if the culture had been positive, i.e. the kidney is drained for some days by percutaneous nephrostomy before ureteroscopy.

Together with the fixation of the ureter to the superficial trigonal musculature, the shape of the ureteral orifice and the length of intramural portion of the ureter are responsible for the prevention of vesicoureteral reflux (Tanagho et al 1968, Schulman 1977). Theoretically, alterations of the ureterovesical junction from forceful dilatation of the intramural ureter could be expected to result in vesicoureteral reflux, but this is rare. In a late follow-up study of 42 patients subjected to intraureteric ultrasonic lithotripsy Stackl & Marberger (1986a) observed reflux in 2 patients (5%). Reflux was moderate (grade 1 or 2) in both, the patients were asymptomatic and the urine culture remained sterile. The ureters were routinely dilated to 12 F with teflon dilators. Ford et al (1984) also observed mild reflux in 1 of 10 patients studied 3 months after ureteroscopy. Acute ureteral dilatation and insertion of the ureteroscope is certainly the most traumatizing phase of the procedure, yet it appears well tolerated. The elasticity of the ureteral wall seems to reduce the trauma of instrument insertion to a degree that results in practically no permanent functional impairment. Reflux is probably of minor importance. There is common agreement that sterile reflux causes no damage to the kidney (Ransley & Risdon 1978).

Ureteral strictures

The development of a ureteral stricture subsequent to ureteroscopy is certainly the most worrying possible complication. Theoretically it could occur as a result of direct trauma with subsequent scar formation, in particular after circumferential denudation of the mucosa. Thermal damage from prolonged activation of an ultrasonic probe and insufficient irrigation could be other causes. Periureteral extravasation of urine is known to cause periureteral fibrosis, particularly when infection is present (Boddy et al 1988). Finally, impacted stones may result in severe inflammatory reactions of the ureteral wall and this may aggravate the fibrotic reaction to any of the injuries.

The true incidence of strictures after ureterorenoscopy is difficult to evaluate.

The experience of the surgeon, the extent of dilatation, the shape and type of the instrument and perhaps also the level of the stone may be additional factors of aetiological importance. Most recent reports on iatrogenic strictures after endoscopic stone manipulation compile case reports, which were usually referred to one centre from different urologists and therefore do not give the true incidence in a consecutive series of patients (Biester & Gillenwater 1986, Lytton et al 1987, Chang & Marshall 1987, Kaufman 1984, Kramolowsky 1987). Whereas Lyon et al (1984) observed no stricture formation at all after ureteroscopy in 142 patients, Kramolowsky (1987) reported a 5% stricture incidence, mainly after perforation, with no correlation to the type of dilatation or postoperative stenting. In a retrospective analysis of 236 patients subjected to ureteroscopy, we observed only 1 patient with stricture formation in the immediate postoperative period (Stackl & Marberger, 1986). Perforation occurred in 8%, but stent drainage and occasionally nephrostomy drainage reliably prevented stricture formation; Lytton et al (1987) reported the same experience. The need for intrarenal stone disintegration extends the operative time, increases the risk of extravasation and, in general, complicates the procedure. Nevertheless, in 120 patients subjected to ultrasonic lithotripsy we observed no stricture formation (Stackl & Marberger 1988) and Fuchs (1988) recently presented a similar experience. From analysis of the reported cases, mechanical trauma, in particular from uncritical dilatation and use of stone baskets, followed by improper ureteral drainage, seem to be the main factors responsible for stricture formation. The patients immediately have problems starting from the operative procedure, and the stricture always seems to form in the first 6 weeks after ureteroscopy (Kramolowsky 1987, Stackl & Marberger 1986a). If the patient has an unobstructed collecting system at this time, as documented by ultrasonography, and the clinical course is uneventful, the risk of late strictures seems minimal.

With 'fresh' strictures after ureteroscopy endourological management is more successful than with most other types of ureteral strictures. If obvious injury of the ureter is noticed at the time of ureteroscopy, but ureteral continuity is still preserved, reliable drainage of urine is imperative. In general, a correctly placed ureteral stent is adequate, but if stent drainage appears to be insecure, we do not hesitate also to insert a nephrostomy. The nephrostomy is placed only to prevent urinary extravasation. As the ureter may dry up, it may not prevent stricture formation (Chang & Marshall 1987). If a stent cannot be placed at the time of the original procedure, this should be attempted in the antegrade direction via the nephrostomy tract as soon as possible. With rather severe ureteral damage the stent should be left in place for 4 weeks. After stent removal the patient is followed-up carefully with at least an intravenous urogram after about 1 week, and repeated renal ultrasonography.

Strictures are treated early. Balloon dilatation is successful in at least 50% of the short strictures. Meatal stenosis at the ureteral orifice can be treated by meatotomy with endoscopic scissors, provided the orifice can be identified. Strictures in the intramural portion can occasionally be corrected by incising directly onto the dilated intramural segment of the ureter, very much with the same technique as for intravesical ureterotomy. Strictures at the ureteropelvic junction are corrected by pyelolysis with success rates well over 80% (Korth et al 1987). Using semiflexible cutting knives, which are directed over a guidewire, or modified ureteroscopes with a cutting knife transported under vision, short ureteral strictures may be treated successfully with a technique very much similar to urethrotomy techniques; Korth et al (1987) reported success even with obliteration of ureteral segments. Usually, however, once a guidewire cannot be passed through the stricture, any more endourological treatment attempts fail. The procedure chosen for open surgical correction depends on the location of the stricture and its length. The techniques are described in detail in Chapter 8.

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Chapter 7

Complicated stones: ESWL and endourology

J M Fitzpatrick

Introduction

It is easy, in the abstract, to define strict laws for managing calculi in the urinary tract. Unfortunately, in many cases, such stones occur not as simple isolated fragments, but as complicated problems associated with significant morbidity. In the past the decision on how to manage these calculi was easy, in that a large loin incision would give excellent exposure to the kidney or upper ureter, a Rutherford Morrison or a transverse suprapubic incision ensured access to mid- or lower ureter, and the problem was solved, albeit with significant postoperative pain. Lesser incisions than this, for example the lumbotomy incision, which went through skin, fascia and aponeurotic tendon, would give a limited exposure, but virtually no postoperative symptoms.

Significant and gradual advances in the open management of renal calculi took place throughout the late 1970s and early 1980s. At the same time, percutaneous approaches to the kidney were being developed. These meant a shorter hospital stay for the patient, associated with a decrease in morbidity, but an increase in the range of operative techniques was required from the urologist, in addition to the incorporation of the 'new technology', which was a major breakthrough. These new changes were adopted quickly by urologists throughout the world, and the comparison of this early acceptance of 'minimally invasive' procedures with other surgical specialities who were slower to do so, was marked. It is certain that the new freedom with which urologists accepted the science of endourology advanced the specialty very greatly. It then became clear that the patients' best interests were ensured by smaller incisions, even if surgery was made somewhat more of a challenge.

It is interesting to note that, even as these considerable changes in endourology were being made, even greater advances in technology were revolutionizing the management of stones: those of extracorporeal shock wave lithotripsy. This meant that minimally invasive surgery in urology was being progressed to its ultimate goal, the non-invasive management of urinary calculi.

One of the byproducts of these advances was that the treatment of urinary calculi was becoming much more complicated. In the past a patient who had presented with a renal calculus and an upper ureteric calculus, would have had both stones removed through a single incision, and the simplicity of this procedure was used by some to advocate the retention of open stone surgery. In addition, the question was asked, if a stone from the kidney and from the upper ureter could be removed concurrently through a lumbotomy incision, and the patient discharged from hospital in three days without pain, where was the need for percutaneous stone surgery?

The management of staghorn calculi has always been a problem for urologists, with a combination of major surgical procedures with the risk of renal functional loss and subsequent stone recurrence. It has been accepted that in open removal of such stones, total clearance is the norm, and anything else unacceptable because of the resultant high incidence of recurrence. The pain of the incision (which lasted for anything up to six weeks after the operation), and the fact that patients did not appreciate either an operation or a scar, meant that the urologist was required to change his approach and adopt the new techniques.

Unfortunately, this meant that access to extracorporeal shock wave lithotripsy was now required in the management of urinary calculi. Initially, the complexity of these machines and their cost prevented a widespread availability. With the advent of second generation machines, the cost decreased, the requirement for anaesthesia virtually disappeared, and many machines could treat stones without inflicting pain and, in most cases, without requiring a hospital admission.

Many debating points have arisen out of the new technology. Although it is clear that morbidity, complications, and postoperative pain have been reduced significantly, the question of cost effectiveness is constantly being mentioned. A randomized controlled clinical trial can never be performed, because informed consent of a particular patient will ensure that the open surgery arm of such a trial will be undersubscribed.

The purpose of this section is to review the more complicated problems of management of urinary calculi in the light of modern technological advances. It is clear that endourology and ESWL have individual roles in the management of such stones, but the difficulty lies in the integration of these techniques.

STAGHORN CALCULI

The history of the management of staghorn calculi has evolved gradually over a number of years. This has been detailed elsewhere in this book. After the initial conservative approach to these stones and non-operative management of earlier times, it became clear that complete surgical removal of staghorn calculi was required to prevent serious complications. This was highlighted by two studies in the 1970s (Blandy & Singh 1976, Rous & Turner 1977), which reported not only a high morbidity but also a high mortality in patients with untreated staghorn calculi. The obvious complications associated with this condition which lead to a sick patient and difficult surgery subsequently, are pyonephrosis, perinephric abscess and xanthogranulomatous pyelonephritis.

As the years went by a number of operative procedures evolved in the management of staghorn calculi. It had become clear that not only clamping of the renal artery in order to maintain a bloodless field, but also the incision into the renal parenchyma, tended to cause a significant loss of renal function postoperatively (Fitzpatrick et al 1980). The extended sinus approach to the renal pelvis, popularized by Gil-Vernet (1965) ensured that many staghorn calculi could be removed without an incision into the renal parenchyma. Anatomical principles were applied to attempts to minimize the trauma to the renal tissue incurred during nephrolithotomy. Marshall et al (1965) attempted to place an incision on the lateral convex surface of the kidney, hopefully avoiding the terminal arterial supply to the kidney. The 'bivalve' operation gives excellent exposure to the stone fragments within the kidney, but Maddern (1967) showed that this particular incision into the renal parenchyma caused severe damage to the pig kidney and, in addition, that the sutures used for securing haemostasis were traumatic and also associated with loss of functioning renal tissue.

Smith and Boyce (1968) and later Boyce and Elkins (1974) showed clearly that the vascular line of Brodel was the line of demarcation between the blood supply of the anterior and posterior segmental branches of the renal artery. This could not be found by a blind incision into the renal parenchyma, but only by defining carefully the intersegmental line by occluding the posterior segmental branch of the renal artery and injecting methylene blue dye. The incision would then be extended from this surface projection towards the calyceal necks with excellent exposure. Outstanding complete clearance rates were reported by Boyce and Elkins (1974) using this method.

Similar results using a different technique were suggested by Wickham et al (1974), who introduced the radial paravascular incision. The value of this incision was that it was placed between the interlobular arteries to the renal cortex, in parallel with them. Other attempts at preserving renal function during nephrolithotomy for staghorn calculi advanced the art considerably.

The use of hypothermia (Wickham et al 1967, Marberger 1979) and inosine (Fernando et al 1976, Wickham 1979, Fitzpatrick et al 1981), can prevent future loss of function during ischaemic renal surgery. The use of the Doppler probe to localize intrarenal vessels (Fitzpatrick et al 1984) and the infrared photo coagulator (Grainger et al 1986) lessened further the effect of the incisions into the renal parenchyma.

One problem associated with the assessment of the various techniques associated with the management of renal staghorn calculi is the absence of the universal adoption of a classification of such stones. In many studies they are referred to as 'partial' or 'complete', but it is clear that this does not present the total picture in a way that comparisons can be made between individual series.

It would seem reasonable that a classification should be adopted in order to standardize the management of this condition. Wickham (1979) introduced the following staging system:

Grade I
a. Small immobile stone
b. Small mobile stone

Grade II
a. The large solitary calculus

Grade III
The large diffuse calculus
a. Staghorn calculus
b. Diffuse multiple calyceal stones

Grade IV
The severely damaged kidney

Although this was helpful and clear, there were some areas of stone disease not quite covered by this classification. In 1984, Rocco et al introduced a further surgical classification of renal calculi. This was quite complicated, but appeared to cover every aspect. The letter **C** was used to indicate that a calculus was present:

C1 Single or multiple calculi capable of spontaneous passage
C2 Large single calculus in the pelvis
C3 Single or multiple calyceal calculi not capable of spontaneous passage
C4 A partial staghorn calculus involving one or two calyceal groups
C5 Staghorn calculus filling the pelvis and all the calyces.

A subdivision of **C3** and **C4** showed the exact position of the stones: **P, S, M, I,** indicated the pelvis, the superior, middle or inferior calyces. There were further subdivisions in this classification clarifying anatomical abnormalities or parenchymal loss. Although it was complex, a stone in the kidney could indeed be classified clearly and comparison between different reported series be made.

Further attempts were made by urologists in the United States of America to classify stones in the upper urinary tract; Griffith & Valiquette (1987) introduced the concept of the PICA-burden. The aim of this staging system was to stratify the stone patient population according to stone factors and anatomical abnormalities. It was again a complicated staging system referring to the three cavities of the renal connecting system: **P** (Pelvis), **IC** (Infundibulo Calyceal), **C** (Calyceal), with **A** indicating anatomical factors such as obstruction. There was a further classification for ureteric stones.

Although these two classifications are all encompassing, they have a significant drawback in that they are extremely complicated. If a staging system is difficult to understand and involves the use of a long list of letters and numbers, it will not be universally accepted and the consequence was that in many studies of the management of staghorn calculi only drawings are used to describe the individual stones treated, which, in my opinion, adds further to the confusion.

Percutaneous techniques in the management of staghorn calculi added a new dimension, which enabled patients to become stone free without significant morbidity. This was also shown to be a safe technique which did not impair renal function (Alken et al 1981, Wickham & Kellett 1981, Marberger et al 1982, Webb & Fitzpatrick 1985, Marberger 1986). Coincident with the development of percutaneous surgery, extracorporeal shock wave lithotripsy (Chaussy et al 1980) was shown to be effective and safe for the treatment of renal calculi.

Percutaneous nephrolithotomy was used initially to remove small renal calculi, but various forms of energy were introduced in order to manage larger calculi; ultrasonic and electrohydraulic lithotripsy and later the pulsed dye laser and Q-switch laser helped to clear the kidney of large calculi. At the same time, ESWL was being used to treat small uncomplicated renal calculi (Chaussy & Schmiedt 1983), but the indications for this form of treatment were expanding and subsequently 70% of all stones were managed in this way (Eisenberger et al 1985).

It was clear that with the introduction of these new treatment modalities, open stone surgery would be relegated to a little-used procedure. At the present time, the indications for open surgery are confined to stones where the fragments are mainly peripheral in the kidney rather than central in the renal pelvis; similarly, in patients with a large stone burden bilaterally, particularly in kidneys with congenital anomalies or pelviureteric junction obstruction. In addition, open surgery may be helpful in patients with complex branching stones in both kidneys with chronic renal failure.

The introduction of the term 'ESWL monotherapy' has tended to confuse matters. It is not at all clear whether 'monotherapy' means a single treatment, or a treatment of a particular staghorn calculus by a single method. Whatever the meaning of the term, it is certainly transgressed by most authors. On reviewing the literature, it would seem that the term 'monotherapy' means ESWL with any number of treatment sessions and, in addition, the insertion of a double-pigtail stent in most patients, with or without the ureteroscopic removal of the Steinstrasse. What it seems to exclude is percutaneous nephrolithotomy or open stone surgery, although it does not exclude percutaneous nephrostomy drainage.

In the days when open stone surgery was the usual treatment for staghorn calculi, urologists were slow to admit to a residual stone rate of greater than 5% to 10%. With the introduction of percutaneous nephrolithotomy, this figure rose slightly to 14% (Winfield et al 1988). The total clearance rate of staghorn calculi after ESWL in comparison with these results is very disappointing. Drach et al (1986) quote a figure at 3 months of 60%; Winfield et al (1988) have a 4-month clearance rate of 42%; Vandeursen & Baert (1990) report that 56% of their 50 patients were free of stones at 3 months or later. In the series from our unit (Thornhill et al 1990), 56% of patients achieved stone-free status by 3 months.

On reviewing the numerous studies into the management of staghorn calculi by extracorporeal shock wave lithotripsy without stone debulking by percutaneous nephrolithotomy, it is certain that complications can be minimized by the prior insertion of either a double-pigtail ureteric stent or a percutaneous nephrostomy drainage tube. If these procedures are not performed, the large stone burden can cause not only a high incidence of ureteric colic, but also septicaemia and, on occasions, pyonephrosis.

The figures quoted above, of a 55–60% clearance rate at 3 months of staghorn calculi treated by ESWL alone, must be considered critically. The average number of treatment sessions is in the region of 4 in most series for large staghorn calculi. The effect on the long-term recurrence rate of this degree of stone clearance is uncertain, but it is unlikely that it would be low. The advantage of course is that subsequent recurrences can also be treated by ESWL as opposed to open surgery.

It would seem that the correct management of staghorn calculi is by initial debulking with percutaneous nephrolithotripsy of the large central pelvic portion of the stone, with subsequent ESWL for any stone remnants in the calyces. That this is the best way of managing staghorn calculi has been suggested from many series (Eisenberger et al 1985, Kahnoski et al 1986, Webb et al 1986, Winfield et al 1988). This approach will result in significantly better clearance rates with a minimal incidence of complications, and in some cases complete clearance by percutaneous nephrolithotripsy will be achieved. Some partial staghorn calculi may well be best treated by ESWL and the insertion of a double-pigtail stent, particularly if this is a struvite stone in the upper pole of the kidney. Although good results are sometimes obtained by initially performing ESWL and then percutaneous removal (Fig. 7.1), it is suggested that large staghorn calculi be treated by prior debulking by percutaneous nephrolithotripsy and subsequent ESWL.

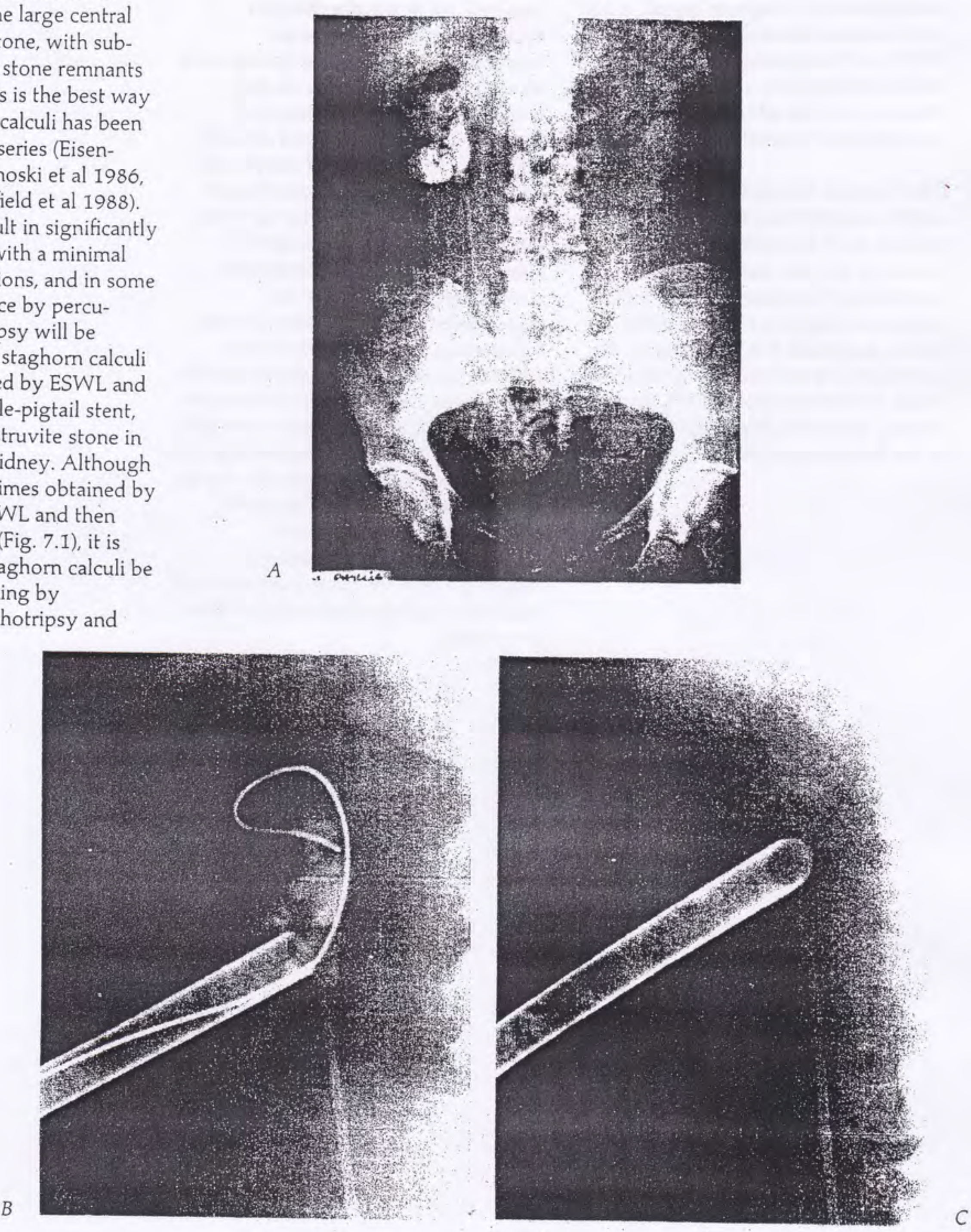


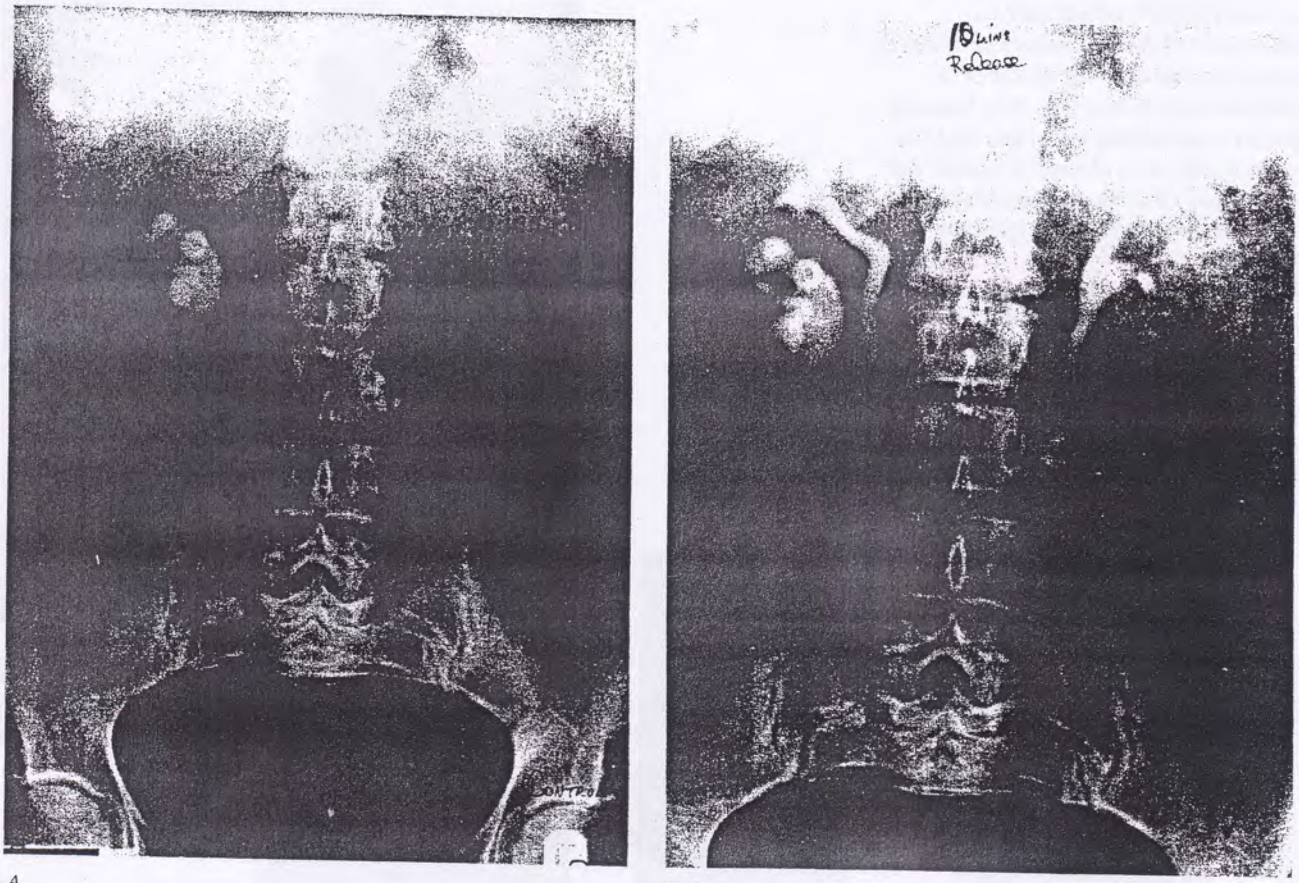
Fig. 7.1

(*A*) Staghorn calculus after one session of ESWL; double-J stent in situ. (*B*) Percutaneous access to calculus. Note 'black adder' ureteric catheter, guidewire and Amplatz sheath in position. (*C*) Clearance after percutaneous nephrolithotripsy with ultrasound.

Another option is the so-called 'sandwich treatment', which has recently been considered as being an appropriate management for staghorn calculi. Initial percutaneous debulking, followed by ESWL and then further percutaneous nephrolithotripsy to attain complete clearance, has the advantage that patients leave hospital stone-free.

If the calculus is associated with a large number of peripheral fragments, particularly if infundibular stenosis is present, it may be that open stone removal may be necessary. In the case of a partial staghorn calculus in the kidney, especially if it is situated in the upper pole but not necessarily excluding calculi in the lower pole, ESWL 'monotherapy' with a double-pigtail stent may be the treatment of choice.

It is also clear that if the management of staghorn calculi is to be standardized, a proper classification of such stones is required. All of the classification systems mentioned above are acceptable, although some do not cover all eventualities and some are too complicated. The management of staghorn calculi has changed radically and needs to be reviewed completely and critically. It is still a complicated problem, which requires that all of the available methods of treatment be considered before a final strategy is decided upon. It must also be remembered that, if the kidney is non-functioning, or if the divided renal function on scintigraphy shows that the affected side contributes 15% or less to the total GFR, a nephrectomy should be performed. Similarly, a staghorn calculus in a non-functioning moiety of a duplex system should be treated by partial nephrectomy (Fig. 7.2). If it is recognized that this procedure is required, a primary stone procedure and secondary nephrectomy will therefore be avoided.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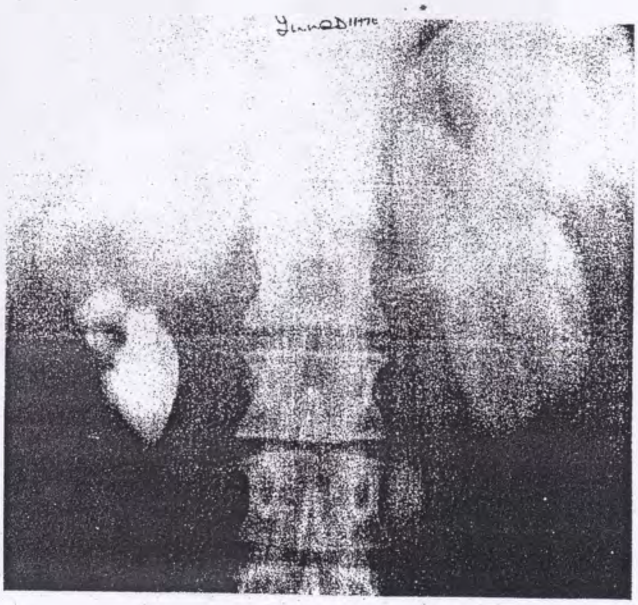
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Fig. 7.2

(*A*) Right-sided staghorn calculus on straight abdominal X-ray. (*B*) On IVU, it can be seen that the staghorn calculus is in the lower moiety of a duplex collecting system, with no obvious excretion of dye. (*C*) Tomographic cuts of the kidneys immediately after injection of dye show a normal left kidney and normal upper moiety of the right kidney. The lower moiety is non-functioning, confirmed on DMSA scan. At surgery, the lower moiety was found to be virtually completely destroyed, with the ureter joining that of the upper moiety at the pelvic brim. A simple partial nephrectomy was performed.

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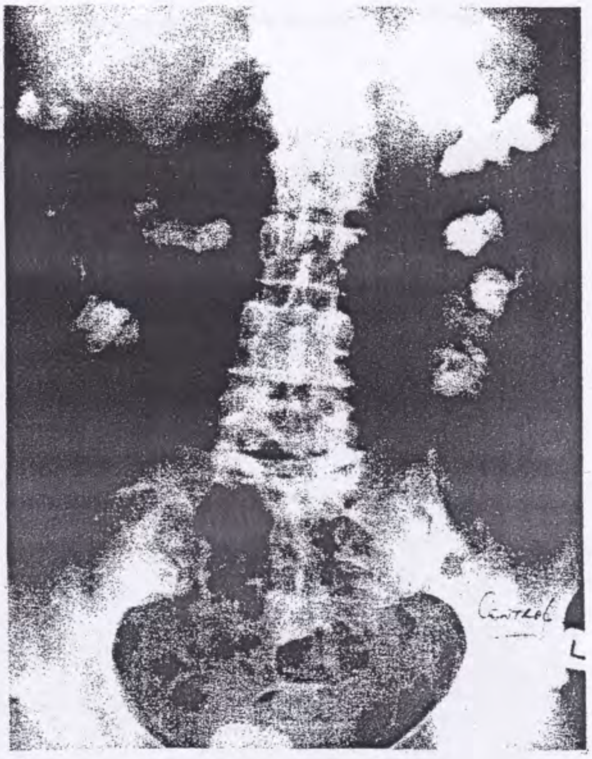
A final problem which may be encountered is the presence of bilateral staghorn calculi in the presence of chronic renal failure (Fig. 7.3). Leaving such stones behind will mean that the patient will have chronic ill-health, not only due to the chronic renal failure, but also because of recurrent infections with subsequent pyonephrosis, xanthogranulomatous pyelonephritis and amyloid. In many cases, removal of the calculi will result in a maintenance of the glomerular filtration rate, preventing its deterioration because of obstruction, and thus saving the patient from dialysis (Witherow & Wickham 1980).



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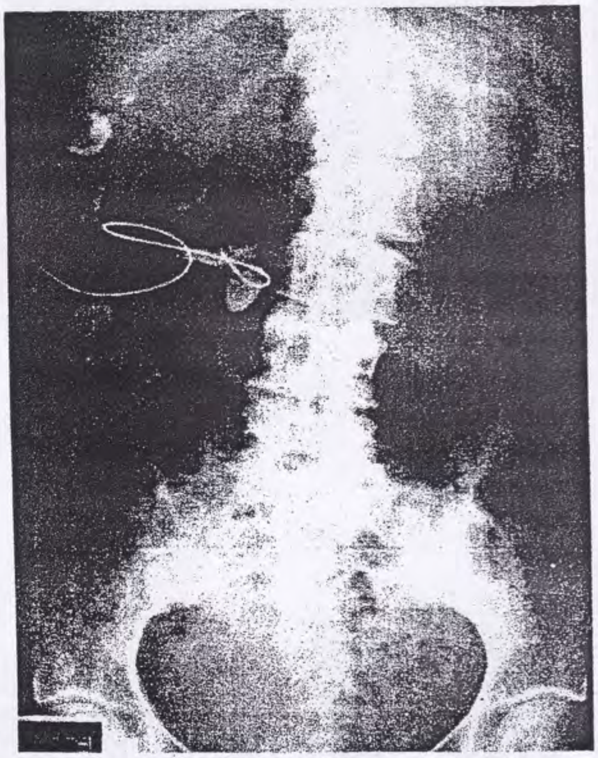

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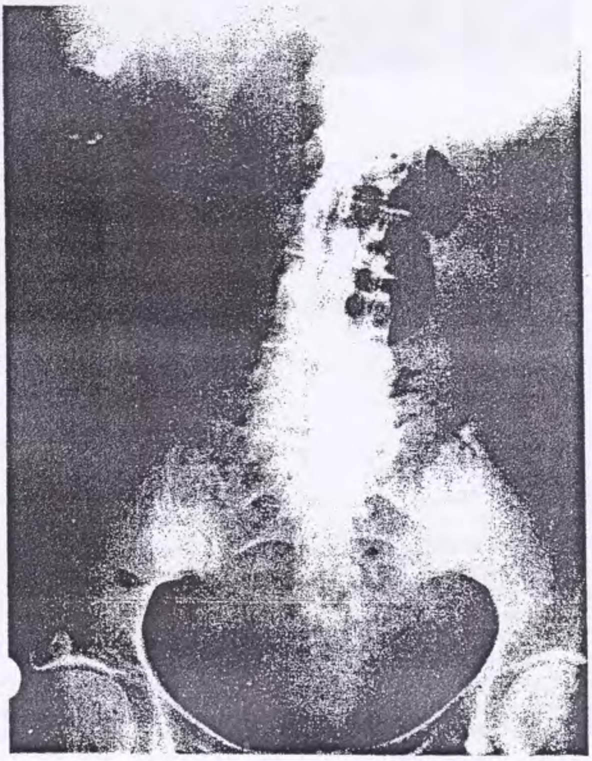

C

Fig. 7.3

(*A*) Bilateral renal staghorn calculi in a patient with a low glomerular filtration rate. (*B*) Open nephrolithotomy has been performed on the left side; percutaneous access to the right kidney, with ultrasonic destruction of the fragments. (*C*) The pelvic fragments have been removed; a second session was required, with multiple punctures, to remove the remainder.

THE MANAGEMENT OF STONES IN CHILDREN

Urinary calculi are relatively uncommon in children and are often related to a pre-existing inherited metabolic defect, or congenital anatomical anomaly, or vesicoureteric reflux. Percutaneous nephrolithotomy may be carried out in children, but in general it is probably inadvisable to carry out this technique in children younger than 6 years, because of the size of the child's kidney relative to that of the nephroscope.

The ideal management of stones in children should include a technique which combines the efficient and complete removal of all of the stone in addition to ensuring minimal morbidity and minimal renal damage. The impact of ESWL on the management of calculi in children has been considerable. A number of series have shown that this can be carried out safely and effectively using either the Dornier HM3 lithotriptor, the Wolf Piezolith and the Siemen's Lithostar (Newman et al 1986, Kramolowsky et al 1987, Kroovand et al 1987, Frick et al 1988, Marberger et al 1989, Neisius et al 1989, Thornhill et al 1990).

There are a number of potential anxieties surrounding the use of this form of treatment in children. The shock waves may have a detrimental effect on growing structures which is not seen in the mature organs of adults and of which we are unaware. Because of the relatively small size of the kidney, there is an increased amount of surrounding tissues included in the high-pressure zone of the shock wave. This has not been shown to be a problem to date, but no long-term observations are available. Any possible prolonged deleterious effect on renal function has also to be established. In none of the studies mentioned above were routine functional evaluations performed pre- and post-ESWL, so that this caveat must be kept in mind when dealing with paediatric stones.

Another potential problem is that the fragments resulting from ESWL may be relatively too large to pass down the child's ureter. The potential complications of the steinstrasse may be difficult to treat because of the difficulty of introducing the relatively large endoscopic instruments available through the child's urethra and into the ureter. In fact, the 9.5 F short ureteroscope can be inserted into the ureter of a child as young as 6 years of age. It is of interest that all of the authors mentioned above commented on the fact that it appeared that fragments passed more easily in children and seemed to be associated with less post-ESWL complications than in the adult in relation to the Steinstrasse and ureteric obstruction.

Although the dose of radiation to the child is low, there is still the anxiety that, because children are more susceptible to radiation hazards than adults, this may be a potential source of problems. This has not appeared to be the case to date and there do not appear to have been any side effects from this. Every attempt is made to keep the radiation exposure as low as possible and the surrounding tissues are protected, not only from X-ray exposure, but also from the effect of the shock waves themselves. The piezolith machines have the advantage that they do not use radiation and that the focal point is significantly smaller than in the other machines.

The question of anaesthesia is also important. Marberger et al (1989), using the Wolf Piezolith, recommend that older children can usually be treated without any medication, but that children younger than 3 years of age should be anaesthetized, because of their tendency to lose concentration and to show a decreased level of co-operation. This statement is important because it is likely that if the child's attention deviates and he decides not to co-operate, the constant movement from the focal point can be frustrating. If some form of medication is being considered, either general anaesthesia with halothane or sedation with intravenous ketamine with nitrous oxide and jet ventilation supplementation are recommended.

In the several series mentioned above, 69 children under the age of 12 years were treated. The youngest patient was 3 months, but 4 others under the age of 1 year were treated. It is difficult to give an opinion as to how old a child should be before recommending that their stone should be treated by ESWL. Certainly in the series reported, there did not appear to be any adverse effects of any significant nature in the patients who were treated. It would seem that, so long as great care is taken to protect the surrounding tissues from the effects of the shock wave and X-rays, if used, this form of treatment can be used in very young children.

All of the authors were enthusiastic about the results obtained with ESWL or piezoelectric shock wave lithotripsy. The clearance rate was complete in 72–96% of the patients treated, with insignificant fragments noted in a further 15–20%. The complication and morbidity rates were extremely low. Some children had pyrexia following treatment, but this was rarely more prolonged than 24 hours. Analgesia was required in 14–20% of the cases. Haematuria was not a significant problem and postoperative hospitalization averaged out at 36–48 hours, although some of the children treated with the Wolf machine were managed as day cases. Additional procedures were rarely necessary. In the series reported by Thornhill et al (1990), no patient had any preoperative intervention, and only 1 required a postoperative procedure (percutaneous nephrostomy). Both Marberger et al and Neisius et al showed that only 2 patients in each series required a preoperative double-pigtail stent, and that none required a postoperative manipulation of any kind. The studies reported to date indicate that the management of urinary calculi in children by shock wave lithotripsy is effective, with a high percentage of complete clearance of stone fragments associated with a low morbidity and low incidence of ancillary procedures.

The questions which have not been answered are those which will have to be studied over a long time period. Pre- and postlithotripsy functional studies will have to be examined in detail, as will any potential effect on renal growth and possible damage to surrounding tissues. The vexed question of hypertension also remains unsolved. It would appear that, in the short term, studies will need to be performed before the anxieties are put to rest.

THE MANAGEMENT OF CALCULI IN THE MID URETER

There are many treatment modalities available for managing ureteric calculi. In the case of upper ureteric stones, the results with ESWL in situ are excellent. Most series (Grace et al 1989, Thornhill et al 1989, Hasun R, unpublished results) report 85–90% clearance of stones by this method at 3 months.

For lower ureteric stones, the treatment of choice is again ESWL, also with excellent clearance rates. In addition, ureteroscopic manipulation of lower ureteric stones and their removal with an alligator forceps, or fragmentation with ultrasound, the laser, or electrohydraulic lithotripsy, offers a range of treatments which will virtually always be successful and associated with a low incidence of complications in experienced hands.

The management of mid-ureteric stones, i.e. stones overlying the bony pelvis (either the sacroiliac joint or the ala of the sacrum), may pose a problem in management. With the patient lying in the standard position, treatment with either first or second generation lithotriptors is impossible. The shockhead will be placed against the bony pelvic brim and, unfortunately, the shock waves will not be able to pass through bone to reach the calculus. For this reason, another form of treatment or a modification of the position of the patient, will be required.

A number of possibilities may be used to overcome this problem. If using the Dornier HM3 lithotriptor, the patient should be placed prone on the gantry, which must be modified slightly in order to perform this. This is described in detail by Jenkins and Gillenwater (1988) and Tiselius et al (1989). In the latter series, 16 patients were treated by 1–3 sessions with up to 2000 shock waves at each session. After completion of ESWL, all patients became free of stones without ureteroscopy or manipulation of any kind except for the use of a ureteric catheter and fluid irrigation during treatment.

The same problems exist for second generation lithotriptors. Marberger et al (1982) reported that, by placing the patient prone on the table of the Siemen's Lithostar, a stone-free rate 3 months of 86% can be achieved. Holden and Rao (1989), using the same machine and the same method, recorded similar results.

Two other alternative methods of treating stones in this position may be used. Either the stone can be destroyed in situ using the ureteroscope, or it can be pushed back into the renal pelvis by flushing (under fluoroscopic or ureteroscopic control) and then kept in the renal pelvis by inserting a ureteric stent. The stone, once safely flushed into the renal pelvis, can then be destroyed by ESWL (the so called 'push-bang' technique). These can be performed at the same session (Albrecht et al 1990).

Of course, as with every ureteric stone, the presence or absence of infection makes a considerable difference. If the stone is impacted and urine culture is positive and the patient has a clinical urinary tract infection, it is essential to insert a percutaneous nephrostomy as a preliminary procedure and treat the patient with antibiotics allowing the infection to subside; antibiotic treatment should be maintained to cover the extracorporeal shock wave lithotripsy. Also, if the stone is impacted in mid-ureter, it may be difficult to flush it back into the kidney without causing trauma to the ureter. Results indicate a low success rate and a relatively high complication rate.

If treating stones in mid-ureter with the ureteroscope, it is essential that the ureter not be traumatized either by the advancement of the ureteroscope, by the treatment itself (particularly if electrohydraulic lithotripsy is being used), or by attempts to disimpact the stone and subsequent flushing. The stone can be managed by any of the above methods, but most patients would almost certainly prefer the non-invasive technique which does not require an anaesthetic, such as is offered to them by ESWL in the prone position. In the 10–12% of cases in which this will fail, one of the endoscopic options mentioned above will be successful.

THE MANAGEMENT OF CONCURRENT RENAL AND URETERIC CALCULI

If a patient presents with a calculus in the ureter and one or more calculi concurrently in the kidney, it may present a therapeutic dilemma (Fig. 7.4). The basic principles in the management of ureteric stones remains the same. If there is evidence of infected urine proximal to the stone, or if the patient has a pyrexia or a tender palpable kidney, it is preferable to insert a percutaneous nephrostomy before contemplating any definitive treatment. Urine taken from the nephrostomy tube can be sent for culture and sensitivity and appropriate antibiotic therapy instituted. This is preferable, in my opinion, to the attempted passage of a ureteric catheter as a defunctioning procedure. This requires an anaesthetic and, if the stone is impacted, may traumatize the ureter. After insertion of the nephrostomy drainage tube and without any major delay, attention can be directed to the stones.

If it is intended to treat all of the stones with ESWL and a nephrostomy tube is in place, the ureteric stone and renal stone can be treated at the same session. If there is no clinical infection and no requirement for a nephrostomy tube, the stone burden must be assessed carefully. If it is anticipated that obstruction may develop following treatment, a double-pigtail stent may be passed in order to overcome this. If a stent cannot be passed, the ureteric stone should be treated in the first instance by ESWL; if this cannot be done the 'push-bang' technique can be employed for the ureteric stone, and the renal stone(s) treated subsequently.

It is also possible to treat the ureteric stone ureteroscopically in situ and the renal stone by ESWL at the same treatment session, with the likelihood of excellent results (Jarowenko et al 1989).

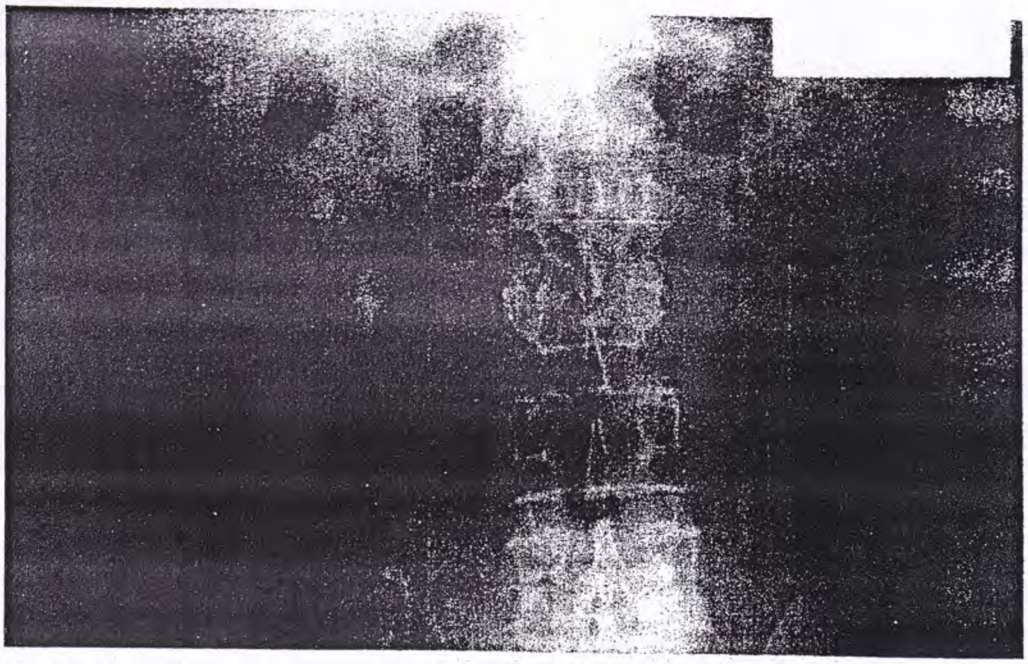

Fig. 7.4(A)

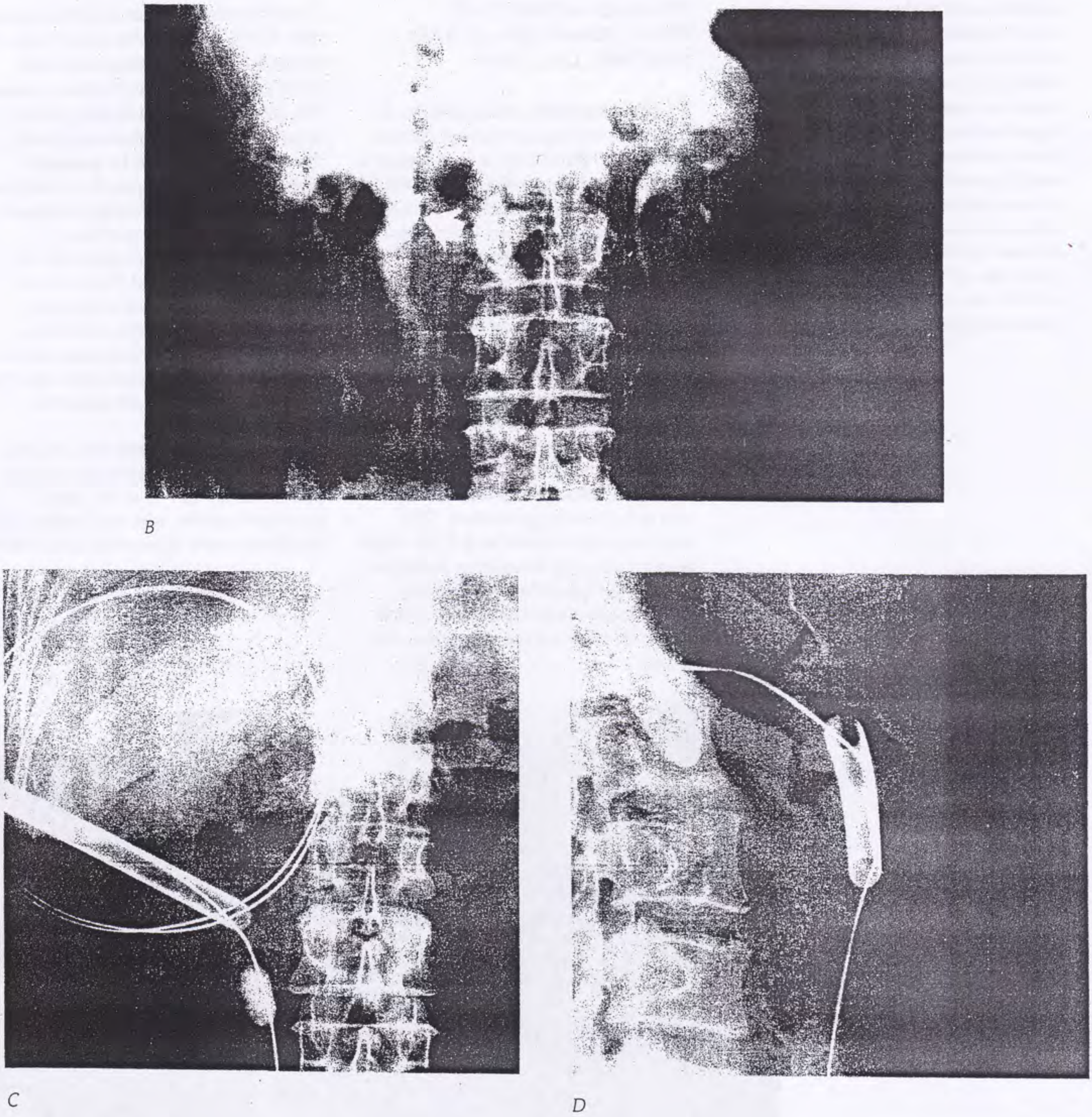

Fig. 7.4

(*A*) Straight abdominal X-ray showing four calculi on the right side. (*B*) IVU shows that three of the calculi are in the right kidney, with the large calculus being in the upper ureter. (*C*) Percutaneous access to the kidney was attained through one of the middle calyces, and the three renal calculi were removed. Because of the ureteric dilatation, the calculus in the ureter was approached easily, and broken up with ultrasound. (*D*) Lateral view shows complete stone removal.

THE MANAGEMENT OF CALCULI IN ASSOCIATION WITH PELVIURETERIC JUNCTION OBSTRUCTION

If a patient has a calculus, or calculi, in association with a pelviureteric junction obstruction, it is clear that both elements of the problem must be treated. The only argument exists as to how best to accomplish this. In the past, open surgery has been used in the management of this situation with excellent results. Once the renal pelvis is opened and dismembered from the ureter the wide exposure thus obtained gives an excellent view of the inside of the renal pelvis and the calyces, allowing for good visualization and removal of all of the fragments of stones situated in the kidney. A standard pyeloplasty can then be performed with excellent long-term results.

ESWL does not have a role in the management of stones in association with pelviureteric junction obstruction, for the obvious reason that after pulverization of the stone, the fragments would be unable to pass into the ureter. This would, therefore, encourage a further degree of obstruction with the possibility of developing a pyonephrosis, or indeed, in the longer term, an almost certain recurrence of the stone.

Within the last decade there has been a surge in endourological procedures and this has been due to the significant technological advances which have taken place during that time. This has affected urology much more than most other surgical specialities, leading to a search for less invasive techniques to treat conditions which have been traditionally managed by open operation. The management of the patient with renal calculi in association with pelviureteric junction obstruction is such an example.

Endoscopic division of the pelviureteric junction has been given a variety of names: percutaneous pyelolysis, percutaneous intubated ureterotomy, percutaneous endopyelotomy, endoureteropyelotomy, and endoureteroplasty, to name but a few. Although virtually everybody uses a different name to describe the procedure, the technique itself has been refined and is now well established (Wickham & Kellett 1983, Badlani et al 1986).

A guidewire is passed retrogradely into the renal pelvis and then the patient is put into the traditional position for percutaneous procedures. The track is established into the kidney, but instead of using the lower pole calyx it is advisable to use one of the middle calyces. Sometimes it may be necessary to go above the 12th rib to do this. After the track has been dilated and the nephroscope inserted into the renal pelvis, the guidewire which had previously been passed will be identified and can then be grasped with an alligator forceps and brought back through the track. The guidewire will therefore be passing through the urethra into the bladder, up the ureter and out through the flank. This is then used as a guide and an incision is made with the Sachse urethrotome posterolaterally at the pelviureteric junction. The incision is made through the ureter until periureteric fat can be seen. At the end of the procedure, a double-pigtail stent is passed antegradely into the bladder and positioned carefully under fluoroscopic control, so that it is certain where it lies. A nephrostomy tube is then inserted through the track for about 5 days. The double-J stent is removed after 6 weeks.

A number of authors have now reported on their results and the results show that the success rate for the above procedure ranges from 60–88%. It has been felt that the results with primary are worse than those with secondary pelviureteric junction obstruction, but in the most recent report (Van Cangh et al 1989) excellent results have also been obtained with primary obstruction.

Another extension of this procedure is to perform it through the ureteroscope and this has also been reported (Inglis & Tolley 1986), but it is best to perform the procedure percutaneously in the instance of it being used in combination with removal of a renal calculus.

Although the results of open procedures for removing stones and performing pyeloplasty are excellent, the less invasive technique combining a removal of the stone percutaneously and at the same session dividing the pelviureteric junction is very attractive and should be offered to the patient. The exception to this would be in cases of PUJ obstruction associated with a reasonably large stone burden in horse-shoe kidneys, where the first option would be open surgery.

SMALL CALYCEAL STONES

The first question which needs to be answered about the management of small calyceal stones is whether they should be treated at all. In the vast majority of cases, small calyceal stones are asymptomatic and do not require treatment unless associated with haematuria, urinary tract infection, or are found to be enlarging or causing pain.

This last indication is a matter of some controversy. Most urologists, when faced with a patient presenting with loin pain and a small calyceal stone fragment would state that the pain is unlikely to be caused by the stone and that the patient should be observed without recourse to therapy. This was especially the case when open surgery was required to remove such calculi, not only because of the large painful scar that is required to remove such a small stone, but also, in some cases, the difficulty in actually finding the stone within the kidney at the time of operation.

With the introduction of less invasive techniques for treating urinary calculi, attitudes may be changing. Andersson and Sylven relieved loin pain in seven patients by removing stones percutaneously in 1983.

Brown et al (1986) removed small non-obstructing calyceal stones from 36 patients percutaneously, and had pain relief in 34 of these. With the advent of ESWL in 1980 it became easier to justify the management of these small stones by means other than non-operative follow up. Mee and Thuroff (1988) reported on their experience of 22 patients with non-obstructive calyceal stones of less than 1 cm in diameter, which were associated with lumbar or flank pain. In none of the cases did there appear to be a relationship between the severity and duration of the pain with the size and location of the stone. All were treated by ESWL and only 3 patients had persistence of stone fragments for more than 3 months. Only 2 of these had persistence of their loin pain, with 1 patient having only a minute amount of gravel left behind and an associated significant improvement in pain. Overall, 20 of 22 patients (91%) had complete or significant relief of their pre-ESWL symptoms. In another report (Netto et al 1989), 30 patients with small non-obstructing calyceal stones were treated by either open stone surgery, percutaneous nephrolithotomy, or ESWL. This was not a randomized trial, but the results were similar to the previously mentioned study, in that 28 of the 30 patients had complete or significant relief of pain.

It is virtually impossible to prove that the small non-obstructing calyceal stones which one sees in clinical practice are responsible for the loin pain which is sometimes associated with them. A lot of time may be wasted in performing complicated diagnostic tests, and if the stones are being managed expectantly, follow-up X-rays will be required on at least an annual basis. Eventually a decision will have to be made and, based on the reports described here, it would seem acceptable that patients with a small non-obstructing calyceal stone be treated with ESWL, a procedure associated with a low incidence of complications.

Percutaneous removal of multiple calyceal stones may be more complicated in that multiple punctures will often be required, in addition to requiring a flexible nephroscope and other instruments to dilate or incise narrow calyceal infundibula (Lange et al 1984). In this instance, when ESWL is not available, it is preferable to manage these stones conservatively.

CALCULI IN HORSESHOE KIDNEYS

The horseshoe kidney is one of the commonest congenital renal anomalies and is the commonest anomaly of fusion of the kidney. It occurs with an incidence of 1 in 400 to 1 in 1800 and is commonest in the male. It has an association with anomalies in other systems and is often complicated by hydronephrosis, infection, or renal calculi. Renal calculi have been reported to occur in as many as 20% of horseshoe kidneys, but the exact reason for this is unknown. It is felt that this increased incidence may be associated with the unusual drainage of urine from the horseshoe kidney, which may be caused by, for example, the high insertion of the ureter, or the anterior course of the ureter over the renal substance. The possibility of an associated metabolic abnormality in patients with horseshoe kidneys has also been noted (Evans & Resnick 1981).

The management of stones in horseshoe kidneys has presented certain difficulties to urologists who wish to treat their patients' stones with the less invasive methods of percutaneous nephrolithotomy, or the non-invasive method of ESWL. The horseshoe kidney lies more anterior than does the normal kidney and, if the patient is obese, the position of the kidney may be too far anteriorly to allow access to the nephroscopist. This problem may be compounded if the stone is lying in the medial calyx at the lower pole. It is therefore recommended that the stones be located accurately within the kidney by CT scanning of the renal areas.

ESWL may fail for the same reasons. Another problem may be that the stone in the medial calyx will be overlying the spine, thus preventing the shock waves from reaching it. Again the stone may be too far forward for the focal point of the machine to coincide with it. A study by Smith and colleagues (1989) shows clearly how, in the patient with normal kidneys, the stone in the renal pelvis may be situated 6 cm from the flank and, of course, lateral to the vertebral body; in the patient with a horseshoe kidney, it can be seen that the stone in the renal pelvis, which is lying anterolateral to the vertebral body, may, in the obese patient, be as much as 16 cm from the flank and this exceeds the distance from the ellipsoid to the focal point of the machine (13 cm). It has also been suggested that the high insertion of the ureter into pelvis of the horseshoe kidney may result in inadequate drainage of fragments from the kidney, leading to high incidence of recurrence or to subsequent obstruction at the pelviureteric junction by a stone fragment.

Jenkins and Gillenwater (1988) showed that, by modifying the HM3 Dornier machine, patients can be placed in the prone position, thus avoiding the problems of positioning the stone in the focal point. In the case of the second generation lithotriptors the patient can be placed in the prone position without any such modifications of the machine.

Smith et al (1989) reported on a total of 17 patients with horseshoe kidneys containing calculi. These were all treated with the Dornier HM3 lithotriptor and 2 patients could not be positioned properly because of obesity. They suggested that to urologists using this machine a 'dry run' was advisable, where the patient would be lowered into the bath without water and with no anaesthetic. One of their patients was asymptomatic and was followed conservatively. Eight of the 14 patients treated (57%) were cleared of their stones by ESWL alone; a further 3 were made stone free by ureteroscopy in 2 and percutaneous extraction in 1, giving an overall success rate of 11 out of 14 (79%).

They reported on one subsequent case who passed blood per rectum after ESWL. This was associated with a narrow spastic segment in the sigmoid colon on barium enema, suggestive of either a submucosal haematoma, or an area of ischaemic colitis. The series reported by Jenkins and Gillenwater (1988) dealt not only with horseshoe kidneys, but also a pelvic kidney and a crossed renal ectopia. The results in the treatment of these patients were also satisfactory and some cases required additional endoscopic procedures.

It would seem, therefore, that some of the old anxieties about the treatment of calculi in horseshoe kidneys can be overcome, leading in most cases to their management by ESWL. In the case of the HM3 Dornier lithotriptor, it would appear that positioning of the stone can be facilitated either by slightly modifying the gantry and placing the patient in the prone position, or by having a 'dry run' procedure before the actual treatment session. In the case of the second generation lithotriptors, it is easy to position the patient on the table and then fully assess whether the stone can be placed in the focal point of the machine.

THE MANAGEMENT OF THE STEINSTRASSE

One of the well-recognized complications of ESWL is the development of a column of stone fragments in the lower ureter after fragmentation of the renal stone. This has succinctly been called the steinstrasse and this word has been universally accepted.

It is a potentially serious complication of ESWL and is, in many cases, not associated with renal colic. For reasons that are unclear after ESWL, even some quite large fragments can be passed from the ureter and into the bladder without the patients developing colic. Unfortunately, in some cases a column of stones form with a larger stone at the apex of this column, and this may become impacted in the intramural ureter.

If this leads to the patient complaining of colic then it would be clear that such an obstruction is indeed present; in some cases the steinstrasse forms silently and so it is important to recognize the possible significance of a post-ESWL urinary infection, or a silent pyrexia or leucocytosis. It is therefore essential that if a patient develops a steinstrasse, a renal ultrasound should be performed to assess whether hydronephrosis and delayed excretion is present. In this latter instance early intervention is required.

The size of the stone may not be relevant to the development of a steinstrasse. In some cases of stones less than 1.5 cm, a steinstrasse can develop, although it must be said that it is less likely to do so than with the larger stones. Weinerth et al (1989) reported on an interesting series of 19 of 650 patients treated by ESWL (3%) who developed what they called a large steinstrasse, defined as being greater or equal to a third of the length of the ureter. They found that 8 of these patients presented with renal colic and 16 with leucocytosis. There was pyrexia in 5 patients, but a further 5 had no symptoms whatsoever.

It is essential that patients with a steinstrasse should be recognized early by performing a straight abdominal X-ray one day and one week after the initial treatment and a renal ultrasound if there is evidence of a steinstrasse. Careful clinical follow-up is also required in order that the symptoms and signs be recognized early. If such a complication develops, associated with obstruction and/or pyrexia, it is essential that the obstruction be relieved without delay.

The management of the steinstrasse can be by the insertion, in the first instance, of a ureteric stent or percutaneous nephrostomy. Subsequent removal of the steinstrasse can be performed by ureteroscopic fragmentation with ultrasound, the laser, or electrohydraulic lithotripsy. It may also be possible to treat a steinstrasse with ESWL, but it should be remembered that the first treatment be directed to the stone at the apex of the column.

Once this has been pulverized the remaining fragments may pass spontaneously. In some cases difficulties may be encountered with the passage of the ureteroscope into the ureteric orifice when there is a calculus impacted in the intramural ureter. In this situation it may be necessary to pass a ureteric stent catheter and leave it in situ for 48 hours; the resultant 'autodilatation' of the ureter by the stent may facilitate the passage of the ureteroscope.

The reasons why a steinstrasse forms are not absolutely clear. It may just simply be that the larger stone, the apex referred to above slows up the drainage of the smaller fragments behind it. In the case of larger stones debulking of the pelvic fragments must be performed by a percutaneous approach prior to ESWL; again in the case of staghorn calculi a double-J-stent should be inserted prior to ESWL if there is no percutaneous nephrostomy.

In spite of these precautionary procedures which would be considered as being essential in the management of patients with large stones, they do not guarantee the prevention of a steinstrasse. What they do seem to prevent is the complications associated with the development of a steinstrasse and so facilitate its subsequent management.

The secret of the management of a steinstrasse is, as mentioned above, the insertion of nephrostomy tubes or stents and stone debulking prior to ESWL in the case of large renal calculi. In addition to this the early diagnosis and careful clinical and radiological follow-up is also absolutely required. The development of a pyonephrosis secondary to a steinstrasse is a significant cause of morbidity and loss of functioning renal tissue for the patient, and must be prevented.

URIC ACID CALCULI

The incidence of uric acid calculi varies throughout the world. Accounting for 5 to 10% of stones formed in the United States and in Europe. Roughly 25% of patients with primary gout will subsequently develop uric acid stones. In Malaysia and other South East Asian countries the incidence of uric acid bladder stones, particularly in children, is rather common.

Although most patients with uric acid stones will have no demonstrable metabolic abnormality, some patients with gout who are treated with uricosuric drugs may be at risk. Another recognized predisposing cause would be the patients with myeloproliferative disorders, particularly if treated with chemotherapy.

In most cases, uric acid calculi are radiolucent and are diagnosed either on ultrasound of the urinary tract or CT scanning, or as filling defects on intravenous urogram or retrograde ureterogram. In some cases small amounts of calcium may be included in the stone and so they appear as ill defined, and sometimes large calculi on the plain abdominal X-ray.

These stones can be reliably dissolved by hydration and alkalinization of the urine. Between the pH range of five to seven the solubility of uric acid increases by a factor of twelve. It is therefore uncommon for some definitive procedure to be required. These stones will break up when subjected to energy waves supplied by ultrasound, the laser, and electrohydraulic lithotripsy. ESWL will also successfully break up the calculi, but visualization on fluoroscopy is impossible without the introduction of contrast medium, either intravenously, or up a retrograde ureteric catheter. Open surgery is never required.

In the event of a patient presenting with unilateral or bilateral ureteric obstruction due to a uric acid calculus, it is necessary to leave the obstruction caused by the stone in the ureter. This can be done by any of three methods:

1. Percutaneous nephrostomy.
2. Insertion of a double-J-stent.
3. Retrograde flushing of the ureteric calculus under vision with the ureteroscope into the renal pelvis, and then insertion of a double-J-stent.

The patient can then be given a high fluid intake and sodium bicarbonate for about 3–4 weeks, in the virtual certainty that the stone or stones will have dissolved. No apparent advantage is conferred by antegrade installation of sodium bicarbonate solution down a nephrostomy tube; it is my experience that this may cause severe pain to the patient. Further imaging of the urinary tract, preferably by ultrasound should be undertaken at 3 weeks, but intravenous urography may be necessary if the stones were in the ureter. With the evidence thus supplied of stone dissolution, stents or nephrostomy tubes can be removed. Particularly in the case of large uric acid stones, a combined approach may yield the best results. The patient should have a double-pigtail stent inserted, be started on oral alkalinization therapy and have ESWL to the stone. This will usually ensure a speedy dissolution of the stone.

CYSTINE CALCULI

The management of cystine calculi has presented a therapeutic challenge to the urologist over the years. As has been explained elsewhere in this book, cystine stones are a feature of cystinuria, which is an inherited disorder characterized by abnormalities in renal handling of cystine, ornithine, arginine, and lysine. Only the high concentration of cystine in the urine gives rise to trouble, as it is the only one of these four which precipitates in the urine, thus giving rise to urinary calculi. Much important work has been performed into the urinary excretion of cystine and its solubility characteristics; these have resulted in the knowledge that a high fluid intake associated with a maximally alkalinized urine can increase the solubility of cystine.

Other problems have also led to a difficulty in the management of these calculi. For example, the X-ray appearance of such stones on the straight abdominal X-ray is described as 'ground glass'. In addition, bony structures such as the ribs can be seen through the stone, and these characteristics enable a reasonably confident diagnosis of cystine calculi to be made on the straight abdominal X-ray. It is this very semiopaque nature of the stones that makes them difficult to localize within the kidney, giving rise to the need for the use of contrast medium for their proper assessment. Also, with the introduction of various types of energy to fragment calculi, the difficulties have become compounded by the crystal structure of cystine calculi making them resistant to fragmentation by the various types of energy.

The basic management of cystine calculi rests on the use of hydration and alkalinization. The urine pH should be kept at eight or less because of the risk of precipitation of calcium with higher levels of alkalinization. D-penicillamine (Crawhall et al 1963) and alpha-mercaptopropionylglycine (Hautmann et al 1977, Pak et al 1986) have been helpful in the management of these patients by markedly increasing the solubility of cystine. Attempts have been made to break down cystine stones by irrigation and, although success has been reported in vitro, to date their value in vivo remains uncertain.

There has been much discussion on the variable results achieved with the use of energy in the fragmentation of cystine calculi. Unfortunately, ultrasound, electrohydraulic lithotripsy, the laser and ESWL are disappointing. The reason for the poor fragmentation of cystine stones is not completely understood, but it may be related to the crystal structure of the stone. The calculi having a uniform crystal structure were least fragile and those with a smooth external surface share the same characteristic; stones with a rough external surface were more fragile and responded better to ESWL (Dretler 1988, Bhatta et al 1989).

These patients should be started immediately on hydration and alkalinization, along with the oral administration of D-pencillamine or alpha-MPG. If there is a stone causing obstruction, then it is best to insert a nephrostomy tube, or to bypass the stone with a double-pigtail stent. Subsequent attempts should be made to disintegrate the stone with either ultrasound, electrohydraulic lithotripsy, the laser, or ESWL. If these methods fail to remove the stone, open surgical removal may be necessary (Fig. 7.5). This is particularly frustrating in the case of a single cystine stone, but in many cases of cytinuria the stones are multiple and bilateral and may be associated with deteriorating renal function. All of these eventualities may justify open surgery because of the rather urgent need to remove obstructing stones and thus improve the patient's renal status.

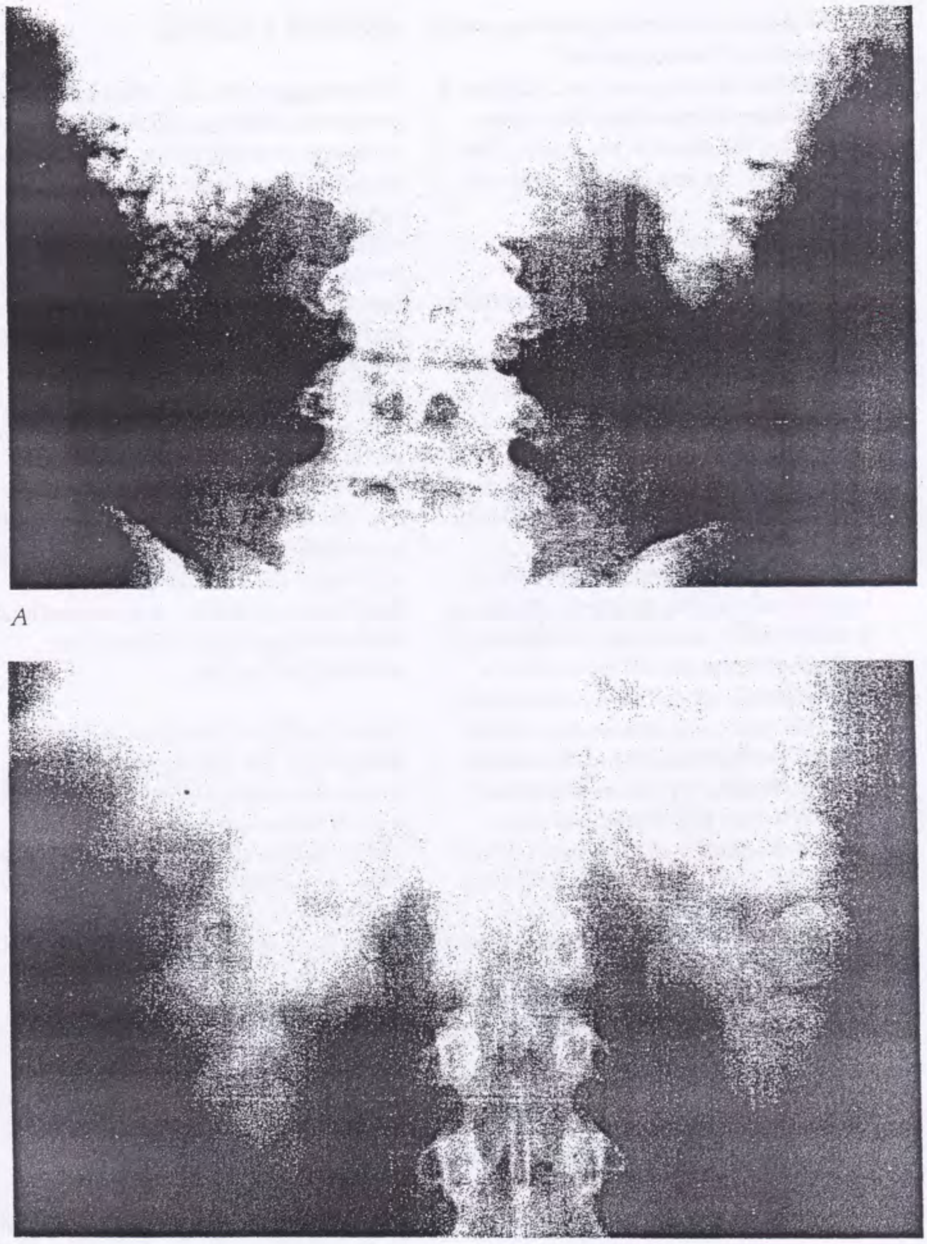

Fig. 7.5

(*A*) Straight abdominal X-ray showing multiple bilateral renal calculi. The patient had cystinuria. (*B*) IVU with tomography shows generalized cortical thinning. The calculi were removed by bilateral open nephrolithotomy.

CALCULI IN CALYCEAL DIVERTICULA

The urologist may, on some occasions, be faced with the management of calculi in a calcyceal diverticulum. Calcyceal diverticula occur uncommonly and are present in less than 0.5% of intravenous urograms. Stones are thought to occur in about 10% of calcyeal diverticula. In many cases they will be asymptomatic, but sometimes they may be associated with chronic loin pain and their removal will be required. It is also possible that calculi in calyceal diverticula may be present in association with other calculi in the same kidney, and in this case their removal will also be required.

Traditionally, in the past, these stones have been managed by open removal. This involved exposure of the kidney and a nephrotomy over the diverticulum with removal of the calculi and then obliteration of the cavity. This could be achieved by marsupialization of the diverticulum and closure of its neck with sutures, or by fulguration.

The advent of extracorporeal shock wave lithotripsy has been of limited help in the management of stones in calyceal diverticula. In most cases the neck of the diverticulum is extremely narrow and would not permit the passage of the stone fragments into the main collecting system. In some cases the neck of the diverticulum is wide and ESWL is of value, particularly where the diverticulum is high and relatively inaccessible.

When calculi have to be removed from calyceal diverticula, the method of choice for doing this is by the percutaneous approach. The percutaneous techniques for the management of this problem are reviewed by Hulbert and his colleagues (1986). They reported on 10 patients with calculi lying within 11 calyceal diverticula. Eight of the diverticula were approached by direct puncture. In some cases it was impossible to pass the guidewire through the narrow calyceal neck into the main collecting system and this was left coiled up within the diverticulum during the dilatation of the track. After removal of the calculi from the diverticulum, the guidewire was passed by direct vision into the collecting system and the neck of the diverticulum dilated in order to allow a nephrostomy tube to be passed through it. The lining of the diverticula subsequently became obliterated by granulation tissue growing around the tube.

In the remaining 3 patients, the diverticulum was approached indirectly; the initial puncture was made through a different calyx and access was achieved into the renal pelvis. With the flexible nephroscope the diverticular opening was located and this was then either dilated or cut in order to remove the contained stone In both of these methods, the use of the C-arm fluoroscopy unit was found to be extremely helpful. The authors found direct puncture of the diverticulum to be the preferable method of access in that the diverticulum could be satisfactorily obliterated in most cases. Even when it was situated in the upper pole, direct puncture was possible between the 11th and 12th ribs.

CALCULI IN TRANSPLANTED KIDNEYS

Calculi may develop in a transplanted kidney and, although this is an uncommon occurrence, it may be a cause of a significant loss of function. The removal of such calculi has in the past caused problems, because open surgical excision of the calculi is associated not only with a significant morbidity, but the definite possibility of major loss of function in the transplanted kidney.

Percutaneous removal of stones in transplanted kidneys has been attempted successfully (Hulbert et al 1986). The relatively superficial location of the transplanted kidney facilitates percutaneous access and potentially allows the possibility for several percutaneous procedures to be performed. In the cases described by Hulbert and his colleagues, the calculi were large and were removed with relative ease. Renal function was not adversely affected by the procedure.

THE MANAGEMENT OF THE OBESE PATIENT

In any type of stone management, the treatment of the obese patient may give rise to certain problems. I remember clearly the large number of patients with staghorn calculi who were obese, when open surgical removal was the only treatment available. Although the fatty abdominal apron tended to slide forwards with the patient placed laterally on the table, there was always a large perirenal fat collection under Gerota's fascia, which bled easily and made exposure of the kidney rather difficult; this is particularly the case when trying to identify the smaller vessels at the upper or lower poles of the kidney. In addition, the large collection of fat in the renal sinus made it difficult to define the plane which must be entered for the extended sinus approach to the renal pelvis. Post-operatively such patients had difficulty with chest complications and, in some cases, deep venous thrombosis.

With the introduction of endourology, these difficulties did not lessen. Access to the kidney through the loin was not as easy as in the thinner person, because of difficulty in assessing the depth of the kidney. Once inside the kidney, 'cheek-to-cheek' problems arose; that is to say, the cheek of the operator resting against the buttock of the patient, preventing the required angulation in order to reach the upper aspects of the kidney. The depth of insertion of the Amplatz sheath might also give cause for concern with the proximal end of the sheath often being flush with the patients skin.

Positioning the patient in the lithotomy position for ureteroscopy is also difficult. The increased fat in the patients thighs make it difficult to enter the intramural ureter at the required angle, and this often means that the leg of the patient opposite to the ureter in question must be lifted by the assistant.

Problems may also be noticed in managing the obese patient by ESWL. Because of the increased thickness of the abdominal wall it may be difficult to position the patient, with the stone always being too high for the focal point of the shock wave. It may be necessary to turn the patient prone in order to perform this satisfactorily.

It is clear that even with the introduction of new treatment modalities for the management of urinary calculi, obese patients may present their own individual problems as outlined above. Although these may make the treatment difficult, they do not make it impossible and can in virtually every case be overcome

THE USE OF URETERIC STENTS IN ESWL

It has been known for a long time that there is considerable value having a ureteric catheter bypassing an obstruction such as that caused by a ureteric calculus or stricture. The so-called 'hydronephrotic drip' that was seen after insertion of the ureteric catheter is a well known and, indeed, a welcome sight, with the knowledge that an acute situation had been overcome.

More recently, considerable emphasis has been laid on the introduction of a self-retaining stent, also known as a double-pigtail stent, to defunction the urinary tract and allow the passage of calculi alongside it, thus preventing any obstruction that might be caused by their passage. Hofmann and Hartung (1989) recently reviewed the different types of ureteric stents currently available and these are made out of the following materials:

1. Thermal plastic biomaterials (e.g. polyurethanes)
2. Thermoset elastomers (e.g. silicone)
3. Hydrogels.

The shape of the stent has also been of interest. Most stents are hollow tubes with side holes at both ends and this design is based on the assumption that most urine drains through the stent. It is uncertain that this is in fact the case, even in the presence of such side holes. This has led to the design of stents with no internal channel but which are made with grooves on the outside, such that the cross-section of the stent is in the shape of a star. It has been suggested (Hofmann & Hartung 1989) that these stents are preferable for use after ESWL treatment, to facilitate the passage of stone fragments.

The studies of Hofmann & Hartung show that, in vivo, most of the urine drainage from the kidney would appear to flow outside the stent. The reaction of the ureter to the stent is initially to develop oedema and thus constriction around the catheter, but secondarily by dilatation and then a decrease in peristalsis. The end result is a widened ureter and a relaxed pelviureteric junction.

In another study, Payne and Ramsay (1988) showed that this ureteric dilatation occurred not because of reflux, but because of the fact that the stents caused renal outflow obstruction. This is a very important observation, in that it showed that double-pigtail stents provide suboptimal drainage of the renal pelvis and would support the concept that, in clinical practice, the presence of a double-pigtail stent does not rule out totally the complications associated with a steinstrasse.

In addition to this, the role of the double-pigtail stent as an aid to the passage of stone fragments must be looked at carefully. Ryan et al (1990) have shown in an experimental study that double-pigtail stents do not facilitate the passage of stone fragments. In addition, Preminger et al (1989) suggested that an indwelling ureteric stent did not contribute to a higher clearance rate of calculi and that it was associated with increased discomfort of the patient following ESWL.

The question of discomfort following the insertion of double-pigtail stents was reviewed in detail by Pollard & MacFarlane (1988) when they reviewed 20 patients evaluated by questionnaire following the insertion of a double-pigtail ureteric stent. Of these 20 patients, 18 suffered one or more symptoms in the upper or lower urinary tract, even when infection was not present.

In a further study, Fetner et al (1989) reviewed an uncontrolled, but reasonably well randomized, group of patients in whom 167 had an indwelling stent inserted and 135 did not, following ESWL. The stratification was based on stone size. The results showed that for stones which were of medium size (less than 3 cm) no benefit was conferred by the insertion of a double-pigtail stent. In addition, symptoms of frequency, urgency and discomfort were increased by the presence of a stent.

These cautionary words are being made lest it be felt that the insertion of a double-pigtail stent is without consequence on the patient. It is certain (Libby et al 1988) that the insertion of a double-pigtail stent reduced complications following ESWL in patients with a large stone burden. In fact, it is clear that ESWL should not be contemplated in patients with a large stone burden who do not have a prior insertion of a double-pigtail ureteric stent. Unfortunately the hydrodynamics of ureteric double-pigtail stent insertion have not been clearly worked out and the consequences of the experimental studies described above have not been assessed fully.

Experimental studies have shown that double-pigtail stents do not facilitate the passage of stone fragments, do not necessarily cause urine drainage through the stent, and would appear to cause dilatation of the ureter around the stent by inducing obstruction. It is therefore clear that, although double-pigtail stents are required when large stones are being treated with ESWL, careful follow-up is essential and long-term expectant treatment of such patients is out of place.

CONCLUSION

The role of endourology and ESWL in the management of complicated urinary calculi has been looked at above. It is certain that there are many ways to deal with any individual problem, and the more complicated that the problem becomes, so does the way of solving it. In the final chapter of this book, a number of problems are proposed illustrating some of the issues raised above and also answered in a practical manner. Endourology has developed remarkably over the last decade and nephroscopes and ureteroscopes, both rigid and flexible, have insured that the entire urinary tract can be visualized endoscopically. In addition, energy probes may be passed through these nephroscopes or ureteroscopes supplying ultrasound, electrohydraulic lithotripsy, or the laser. This means that, in most cases, stones can be broken up in situ by these forms of energy.

It is hard to see how much further endourology can advance. Contact energy appears to have reached its zenith, but it may be that a combination of imaging and fragmentation of calculi may become available; for example, the passage of an ultrasound or MRI probe into hollow organs, giving excellent visualization of calculi in these areas and allowing the possibility of passing energy probes either through or beside the imaging unit.

With the arrival of the original Dornier machine, it was hard to see how further advances on such a magnificent treatment modality could be made. Within a few years, the second generation lithotriptors had arrived. In place of the bath in which patients had to lie, a multimodal table was developed. In place of fluoroscopic visualization of the calculi, ultrasound imaging was developed. Changes in the type of energy and the size of the focal point reduced incidence of pain during the procedure and obviated the requirement for anaesthesia, and in most cases analgesia.

It is to be hoped that further changes will take place in extracorporeal shock wave lithotripsy. The idea that all of the complicated machinery will disappear is an attractive one, and the consequent hope that the imaging and energy sources will be combined in a hand-held unit is very desirable. It is further to be hoped that all of these advances in endourology and ESWL can be added together in order to facilitate the treatment of complicated urinary calculi.

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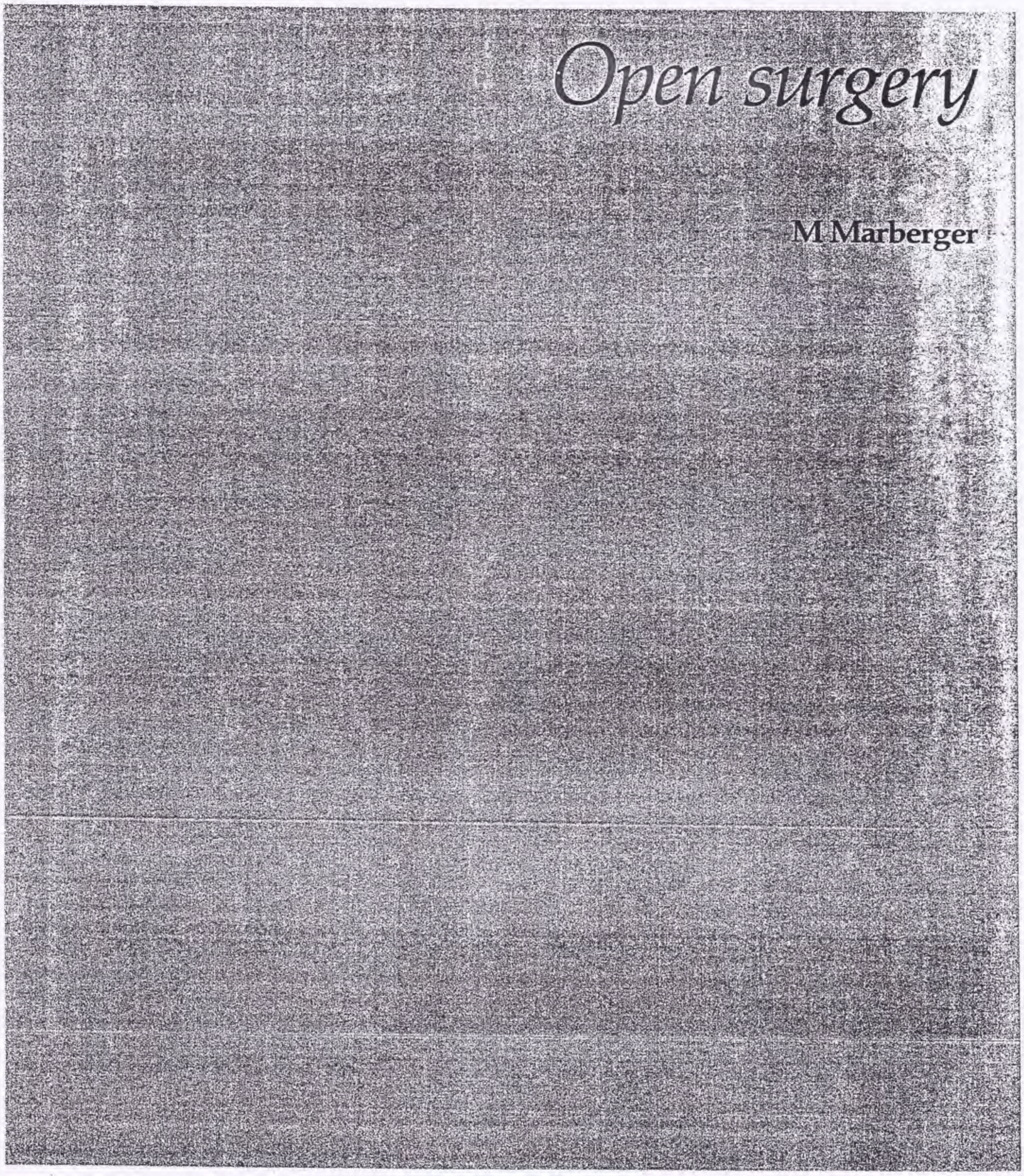
Chapter 8

Open surgery

M Marberger



Introduction

For centuries 'cutting for stone' was synonymous with urology, and less than a decade ago it still made up at least one-fourth of the surgical activity in this field. The development of endoscopic stone surgery and extracorporeal shock wave lithotripsy shattered this tradition: less than 12% of all patients requiring a surgical intervention still need open stone surgery today and the merits of this development are obvious (Fig. 8.1). As a consequence, the craft of open stone surgery is rapidly decaying and future generations of urologists may miss this field in training completely. Albeit rarely needed, it is nevertheless an indispensable segment of the therapeutic armamentarium. It may still be the most rational approach to remove extremely bulky stones and stones in urinary tracts requiring surgical correction of obstruction. Finally, it remains essential in all situations where ablative interventions are needed.

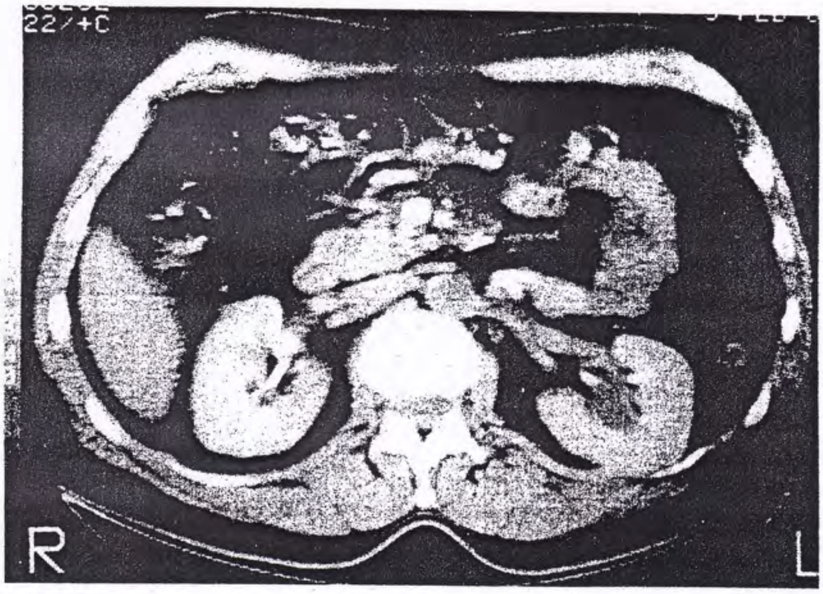


Fig. 8.1

Axial computerized tomography of the kidneys of a 42-year-old patient, 5 years after pyelolithotomy on the left and 4 years after ultrasonic percutaneous nephrolithotripsy on the right side for similar stones; note the severe alterations of perirenal morphology after open surgery.

With less invasive methods of stone removal, a sudden change of the position of the calculus can be met without major problems, even when noticed only during the intervention. In open stone surgery this may result in a catastrophe, with failure to remove the stone and the need for further intervention. The time-honoured rule of precise delineation of the size, number and shape of all calculi and their topography within the collecting system prior to an open surgical procedure remains as valid as ever. A plain film immediately before the procedure is mandatory, even with the largest calculus apparently incapable of changing its position; a fragment breaking off and blocking the distal ureter may require a completely different surgical strategy.

SURGICAL ACCESS TO THE KIDNEY

With simple pelvic stones being ideally suited for percutaneous surgery or ESWL, the posterior lumbotomy incision has practically become obsolete. Although non-muscle-splitting, and therefore unsurpassed in its low post-operative morbidity (Lurz 1956, Gil-Vernet 1965), exposure is limited by the 12th rib above and the iliac crest below. Access to the upper pole or the middle third of the ureter is difficult, and complete mobilization of the kidney or dissection of the renal pedicle virtually impossible without a T-shaped extension of the wound (Lytton 1979). Gil-Vernet has developed special film holding forceps to permit in-situ renal radiology through this incision (Gil-Vernet & Culla 1984). Without them accurate intraoperative contact roentgenology is almost impossible. Although Gil-Vernet removes even difficult calculi via this approach with excellent results, the type of renal stones needing open stone surgery today requires more extensive exposure.

Whereas flank incisions below the 12th rib are virtually always too low for renal stone surgery, a supracostal approach in the 11th intercostal space provides excellent access to the entire kidney with acceptable muscle injury. It is therefore the standard approach in stone surgery today. The oblique and transverse abdominal muscles need only be cut over a distance of a few centimetres and the subcostal and ilio-hypogastric nerves are easily avoided. Since there is no need for rib resection, the wound is easily displayed by a rib retractor. Postoperatively the wound is supported by the ribs and herniation is rare. The length of the incision can be modified to suit the specific surgical problem and the frugal incision for simple pyelolithotomy is easily extended to allow complete mobilization of the kidney (Turner-Warwick 1963, Marberger & Stackl 1986). Lesions in the upper pole or high-lying kidneys may be reached by an extrapleural approach through the 10th intercostal space; the renal stones subjected to open stone surgery today are frequently infected and a trans-thoracic approach is better avoided.

Supracostal, extrapleural approach: The patient is placed in a lateral jack-knife position (Fig. 8.2*A*). The skin incision runs parallel to the upper margin of the 12th rib and distally in the line of the rib. Its length depends on the precise nature of the procedure. For simple operations, an incision along the distal half of the rib extending 5 cm into the abdominal muscles suffices. For more difficult procedures involving complete mobilization of the kidney and intraoperative radiology, the incision should start three fingers' breadth lateral to the dorsal spines and be extended as far anteriorly as required. After the subcutaneous fat has been divided the fibres of the abdominal musculature are incised immediately beyond the tip of the 12th rib with cutting diathermy. The transversus abdominis muscle blends here with the deep leaf of the thoraco-lumbar fascia, which should be divided along the same line. The second and third finger of each hand are now used to sweep the peritoneum off the under-side of the abdominal wall muscles, prior to extending the muscle incision medially as required. The incision should be kept strictly in line with the extension of the 12th rib so as to keep well clear of subcostal vessels and nerves. Once it has been carried as far medially as needed, dissection can proceed in the opposite direction along the 12th rib. The latissimus dorsi and

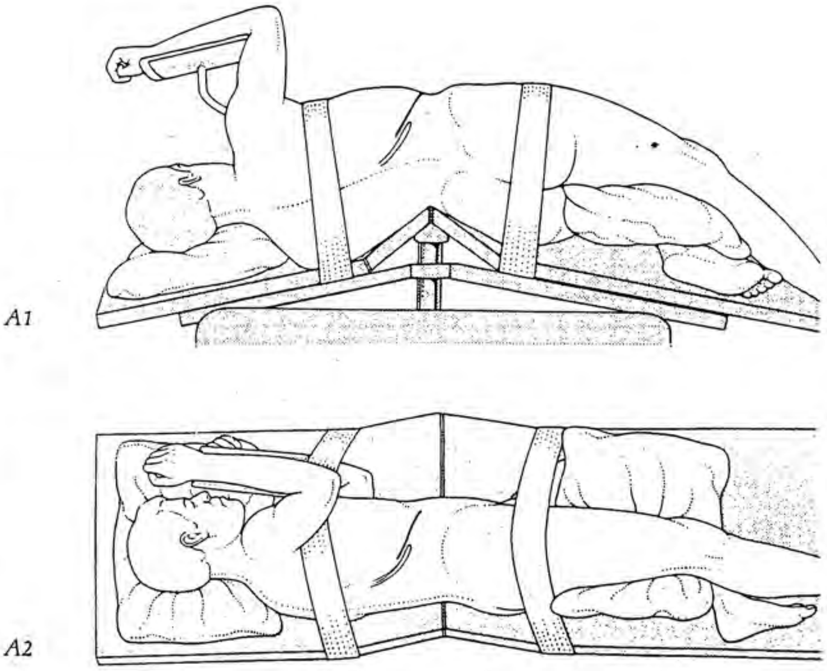


Fig. 8.2

12th rib supracostal incision: (*A1, 2*) positioning of the patient; (*B, C*) division of the intercostal musculature and diaphragm so that the 12th rib can be swivelled outward to expose the renal fascia; (*D*) drainage and closure.

intercostal muscles are divided by diathermy moving backwards along the upper margin of the rib. As the rib is progressively mobilized, the insertion of the diaphragm and the pleural reflection come into view (Fig. 8.2*B*). The subcostal nerve is carefully preserved as the diaphragm is divided flush with its insertion to the abdominal wall (Fig. 8.2*C*). The pleura is pushed away by blunt finger dissection. Depending on the degree of exposure needed, dissection of the 12th rib may proceed up to the vertebral column. After dividing the costovertebral ligament and complete elevation of the crus of the diaphragm, the 12th rib can be swung outwards like a door. Incision of Gerota's fascia in the line of the skin incision allows direct access to the entire kidney and adrenal gland. A rib retractor or a modified Wickham-ring retractor (Wickham et al 1974) permits excellent exposure of the entire field, the blades also controlling the perirenal fat.

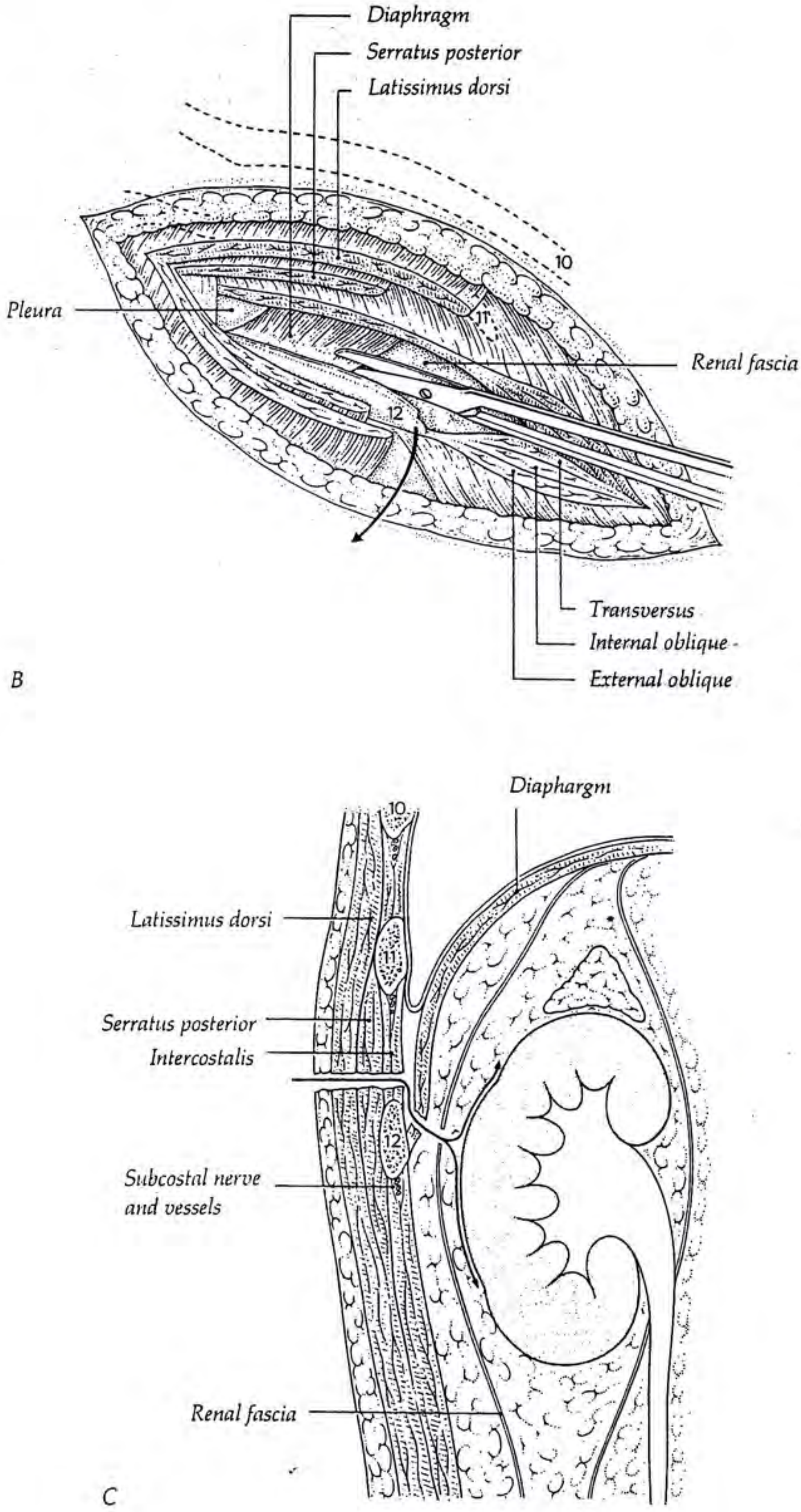
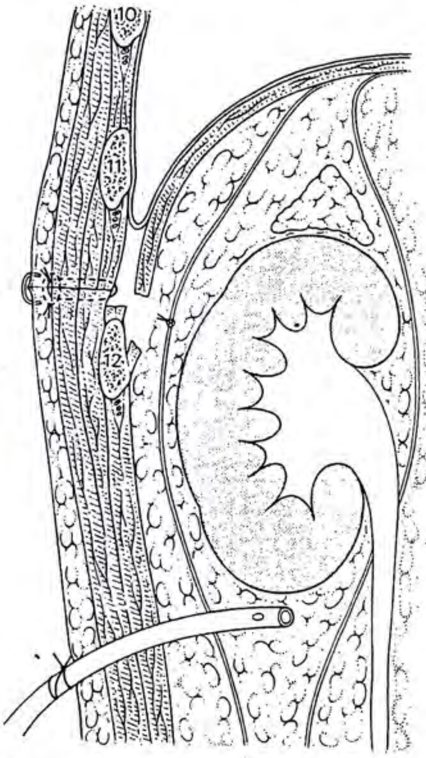


Fig. 8.2



D

The wound drain is brought out in a dependent position through all layers of the abdominal wall and Gerota's fascia via a separate stab incision lateral to the lower end of the main incision. ~~The wound is closed with interrupted, through-and-through polyglycolic acid sutures, which include all intercostal and abdominal muscles to avoid lateral displacement of the layers. The sutures are preplaced and tied after lateral~~ hyperextension is relieved. The superficial muscles and associated deep fascia are, in addition, approximated with a running suture (Fig. 8.2*D*).

In approximately 15% of the supra-12th rib and 70% of the supra-11th rib incision, the pleura is opened accidentally (Marberger 1986). This is usually noticed immediately by air escaping during expiration. In this situation the diaphragmatic crus is completely dissected off the pleura around the lesion to lessen tension, and the rent is closed with a continuous 5-0 chromic catgut suture. It is tied after expansion of the lung by positive pressure ventilation. Airtight closure can be controlled by filling the wound with saline. Bubbles rising from the pleura at expiration signal incomplete closure and the need of additional sutures. In general, the mishap remains without sequelae, but a chest X-ray should routinely be obtained postoperatively. In up to 10% of these patients some marginal pneumothorax may be noticed, but it can usually be treated conservatively.

With extended procedures, more serious effects on pulmonary function may result from the lateral jack-knife position. The contralateral hemithorax is compressed and its respiratory movement is impeded. In elderly patients, particularly with previously impaired lung function, this may result in contralateral atelectasis and effusion (Birch & Mims 1975). Careful correction of intraoperative fluid and temperature alterations, in particular when regional hypothermia of the kidney is utilized, early mobilization and chest physiotherapy reduce these complications. Since hypoventilation due to pain also increases respiratory complications, the 10th, 11th and 12th intercostal nerves should be infiltrated with 6 ml each of 0.75% bupivacaine at the end of the procedure to facilitate early mobilization (Crawford et al 1978). Provided the incision was not carried too far medially beyond the tip of the 12th rib, incisional hernias will not occur. Persistent neuralgia or abdominal wall weakness occur in in 4% of the patients and are more common after secondary procedures (Barry & Hodges 1975).

Surgical access after previous surgery

After previous surgery, access for recurrent disease depends on the individual situation and requirements. Nonetheless, a systematic approach and careful, but concerted, dissection to locate surgical landmarks substantially reduces the complication rate of such procedures (Hohenfellner 1980). The skin incision is placed in order to give the best possible exposure, whilst seeking to avoid regions of previous dissection. Cosmetic considerations have a low priority. The approach of choice is usually an 11th or 12th rib supracostal incision, if necessary with resection of the rib. If an ablative procedure is planned, in particular because of pyonephrosis or with a thoracic deformity an *anterior, transabdominal approach* may be preferable, as the renal pedicle can be exposed directly, avoiding perirenal scar tissue (Linke et al 1978). The peritoneum is opened via a transverse upper abdominal incision. The posterior peritoneum is then incised and dissected off medially. On the left the spleen and on the right the duodenum must both be swept away and carefully protected. The anterior aspect of the kidney and the renal pedicle are now easily identified.

If a *supracostal approach* is chosen, dissection should begin as high as possible in the costovertebral angle, aiming to sweep off the pleura and to divide the crus of the diaphragm. Pleural injuries are only dealt with once the kidney has been completely mobilized. Since the perirenal fat is nearly always fused with the psoas fascia, the subfascial plane of the psoas suggests itself as a primary plane of dissection (Hohenfellner 1980). It is easily developed caudally by blunt dissection to reach the lower pole. The abdominal wall incision is then gradually carried medially to whatever extent allows adequate retraction, if necessary dividing the ipsilateral rectus muscle. If possible, the peritoneum is swept medially. Otherwise it is incised as far medially and as far away from the colon as possible. Once the wound can adequately be opened to insert the retractor, the ureter is identified and snared within the unscarred connective tissue distal to the lower pole. Since an intubated ureter is easier to identify, a ureteric catheter should routinely be passed prior to any re-exploration. With the ureter exposed, there are no further important structures to be spared in direction of the lateral abdominal wall and psoas, so that the scar tissue lateral to the kidney may be divided sharply. The colon and, on the right, the duodenum are then dissected off. Under difficult circumstances it may be necessary to do this transperitoneally and under vision. Once the renal pedicle is identified below these structures, all important anatomical landmarks are identified.

The kidney is now exposed by dissecting the adipose capsule off the fibrous capsule in a plane just above the latter. In the course of this, substantial blood loss may occur from the severed scar tissue. Damage to the capsule and in particular subcapsular dissection should be avoided, since the renal capsule is essential for an atraumatic closure of nephrotomies. The ureter can usually be mobilized up into the sinus quite easily with a curved haemostat, so that the lower pole can be exposed by sharp dissection. Accessory vessels are common in the region of the upper pole and along the medial border of the kidney. In difficult cases stepwise examination of the territory with a Doppler stethoscope may be helpful (Boyce 1984). Large vessels always produce an audible signal and they can be dissected. The remaining scar tissue is divided closely adhering to the renal capsule, so that injury to the adrenal is avoided. The kidney must be mobilized to an extent that a hand can be passed around it and that it can be suspended in a Netelast sling (Wickham 1979), or with umbilical tapes (Boyce 1984). Good intraoperative radiology usually requires dissection of the renal vessels to their point of union with the main abdominal vessels (Marberger & Hruby 1984).

PYELOLITHOTOMY

In contrast to any type of nephrolithotomy, direct parenchymal damage is avoided if the stones are removed through an incision in the collecting system only. Even extensive surgery of this kind does not cause any loss of renal function (Fitzpatrick et al 1980). The concept of intrasinusal pyeloinfundibulotomy (Gil-Vernet 1965) opened the transhilar approach for even the most complex intrarenal calculi.

Extrasinusal (simple) pyelotomy

After entering the retroperitoneal space, Gerota's fascia is incised longitudinally posterior to the kidney, and the adipose capsule is divided, taking care to preserve both structures to facilitate anatomic closure. For simple stones in the extrarenal part of the renal pelvis the kidney need not be mobilized and only the posterior aspect of the lower pole is exposed. The ureter is identified in the fatty tissue and followed in the proximal direction until the posterior surface of the renal pelvis comes into view. The calculus is removed through a transverse pyelotomy, which should preferably be placed close to the parenchyma and well away from the ureteropelvic junction to prevent strictures.

Intrasinusal pyeloinfundibulotomy

In general, stones subjected to open surgery today are more difficult and require exposure of the intrarenal collecting system. With normal anatomical conditions the renal sinus is sealed by a thin diaphragm of connective tissue radiating from the fibrous capsule of the kidney to fuse with the pelvis and the renal pedicle (Gil-Vernet 1965). Behind it, the intrarenal collecting system and the segmental vessels lie embedded in loose fatty tissue. By spreading the arms of curved scissors or a curved haemostat a plane is easily developed between the peripelvic fat and the renal pelvis. Once the diaphragm has been opened along the dorsal aspect of the renal pelvis, the perihilar structures may be lifted off the intrarenal collecting system by blunt dissection. Although the renal sinus varies considerably in its dimensions, it is usually possible to expose the entire pelvis and the infundibula of the main calyces with this technique. As long as dissection proceeds along a plane close to the collecting system, the segmental vessels are retracted with the perihilar fat so that they are neither easily injured nor hinder access (Fig. 8.3).

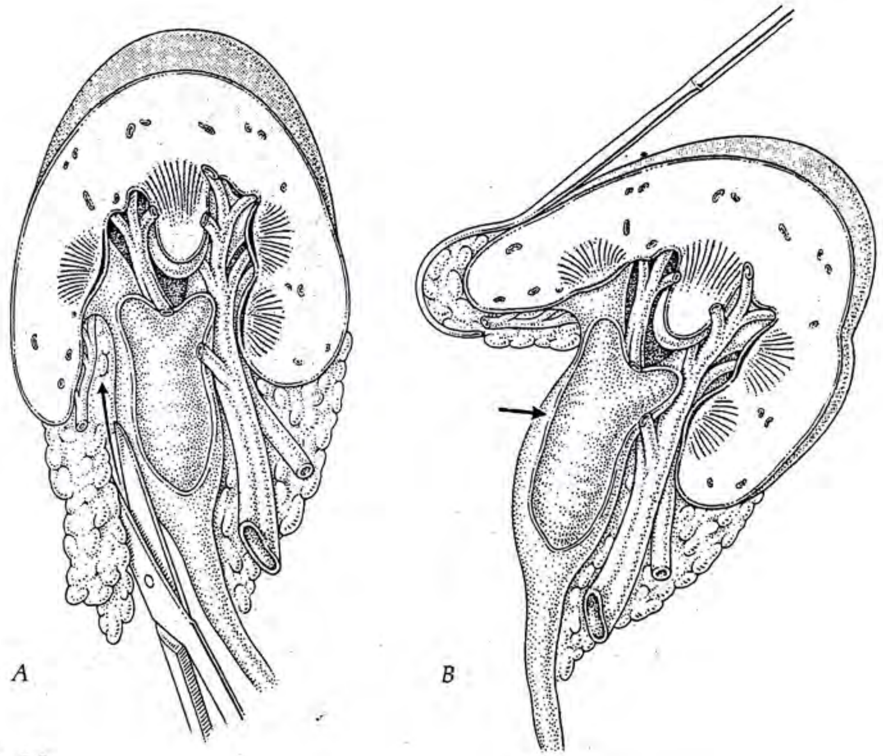


Fig. 8.3

(*A, B*) Intrasinusal pyloinfundibulotomy: exposure of the intrahilar collecting system.

Gil-Vernet (1965) described special retractors which facilitate this manoeuvre. In a modified form with malleable blades and available in various sizes, they can be adapted to any individual situation (Fig. 8.4). They provide not only retraction of the perihilar structures, but also protection of the retracted vessels from inadvertent injury during intrarenal dissection. The latter may be carried out either with a Lahey dab or, most effectively, with wet ribbon gauze which is gradually packed into the cavity as it develops and which is held under the retractors (Gil-Vernet 1983).

Severe perihilar inflammation or previous surgery may obliterate the usual planes of dissection. Despite this, it is usually possible to develop the renal sinus as long as dissection proceeds along the muscular layer of the collecting system. The scarred connective tissue is thus lifted away with the peripelvic adventitia. Sharp dissection may be needed, but since all the major vessels lie outside the adventitia and are protected by the retractors, vascular injury is most unlikely. As dissection proceeds more deeply into the pelvis, small veins may be opened, but venous haemorrhage is easily controlled by pressure with the retractors. By patting the retractors with neurosurgical sponges, the renal parenchyma is protected from retractor pressure and the surgical field is cleared as oozing blood is absorbed.

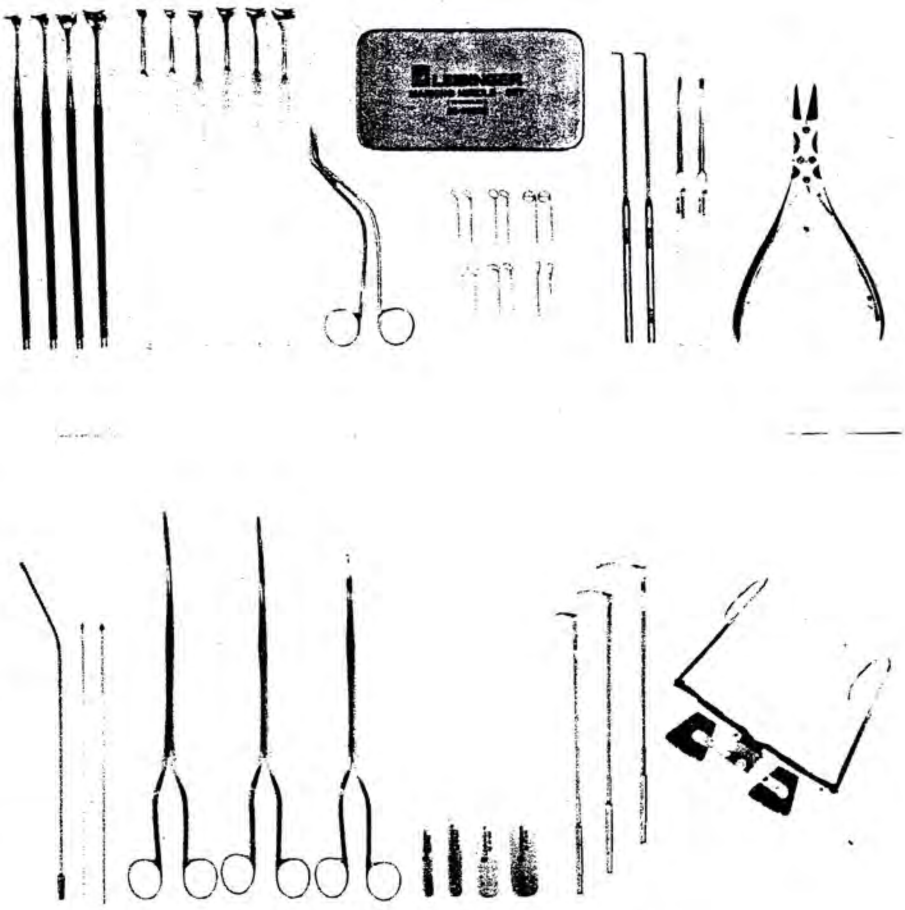


Fig. 8.4

Special instruments for renal stone surgery: hilar retractors with malleable blades, scissors for intrahilar incision of the collecting system, marking needles for intraoperative roentgenography, stone hooks, parenchymal dissectors, stone cutter, malleable probe for irrigation or aspiration, malleable nephrostomy tube guides, stone forceps, vessel clamps with malleable shaft and adaptable closing pressure, optical loop (Leibinger, FRG).

The muscle fibres of the renal pelvis take a circulospiral course (Gil-Vernet 1983) with a very small angle of inclination. A transverse incision parallel to the longitudinal axis of the kidney and roughly at a right angle to the course of the ureter therefore causes least damage and limits the risk of tearing into the pelviureteric junction. Naturally, this basic incision must be adapted to the individual shape and position of the stone: for very large stones the incision is U-shaped, with its convexity toward the ureter and its branches extending upon the stone-bearing calyceal infundibula. The renal collecting system is so abundantly vascularized that even the division of multiple vessels will not impair healing, but the pelviureteric junction must be spared. The more the incision lies within the sinus, the less likely extravasation of urine is to occur from poor closure, as the incision is covered by parenchyma once the retractors are released (Fig. 8.5).

The stone is extracted with stone hooks or atraumatic stone forceps. With branched stones the pelvic portion of the stone is first tilted out of the renal pelvis and the shorter calyceal extensions are then developed through generous incisions of the affected infundibula. Finally the entire stone is lifted out by gentle rotation along the axis of the remaining calyceal extensions (Fig. 8.6). Ideally the stone should not be broken. If it is too branched for extraction in one piece, it is divided under direct vision with a special stone cutter (see Fig. 8.4).

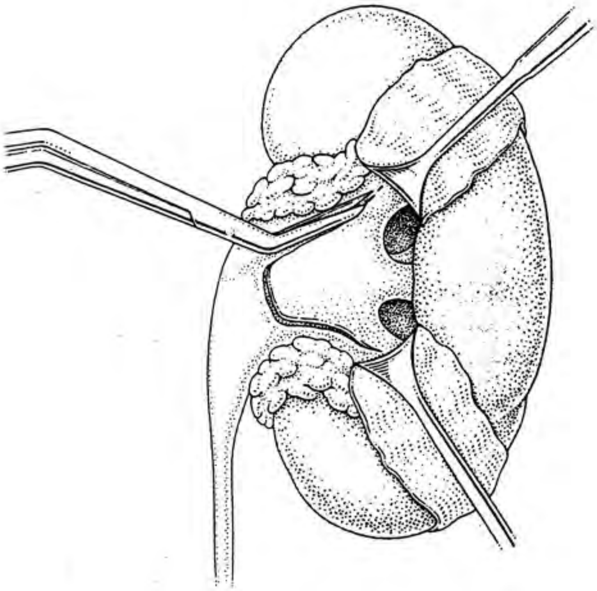


Fig. 8.5
Intrasinusal pyeloinfundibulotomy: incision of the collecting system.

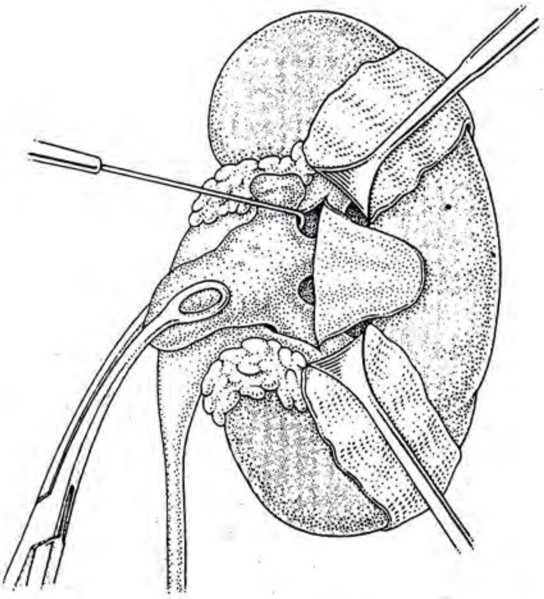


Fig. 8.6
Intrasinusal pyeloinfundibulotomy: stone removal.

Correct intrasinusal dissection will expose the infundibula of the main calyces of the upper and lower poles and of the anterior calyces. Residual stones can then be retrieved from these under direct vision with fine forceps. Peripheral fragments are best removed by flushing of the affected calyx under direct vision. Its effectiveness depends on a high flow rate and on a good jet of saline, and both are supplied with a malleable metal catheter and saline administered from an infusion bag in a pressure cuff (Fig. 8.7) (Wickham 1979); dental or surgical wound irrigators are more effective, but also more complicated. During intrarenal flushing, the area around the pyelotomy should be protected by gauze to prevent stone fragments from being lost in the wound; on later radiographs they would be indistinguishable from residual stones.

An expert will be able to locate and remove residual calculi in secondary calyces by palpation with a malleable probe, but this technique is unreliable in routine use and frequently provokes haemorrhage. Where residual stones are suspected, pyeloscopy is routinely performed. Intraoperative radiology is always needed to confirm complete stone removal (see p. 214).

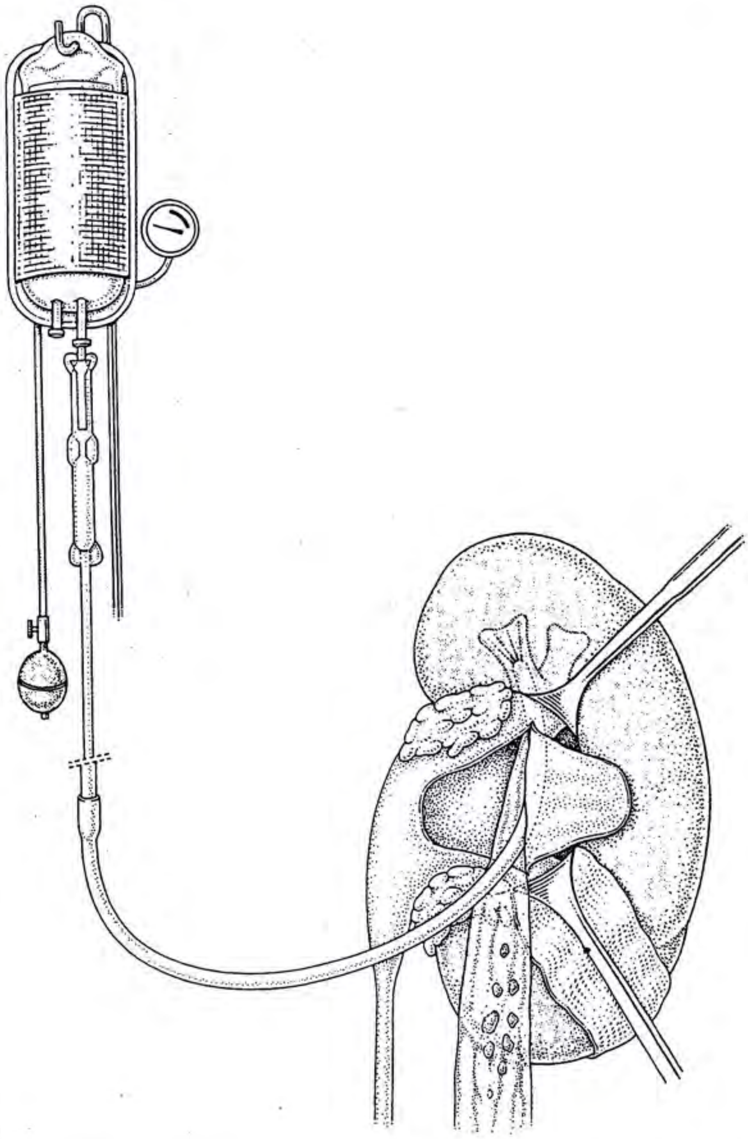


Fig. 8.7
Flushing of the collecting system.

Watertight closure of the renal pelvis is attempted, but not always achieved. Two running sutures of 5-0 polyglycolic acid or chromic catgut are started at the point of maximum convexity of the posterior pelvic flap and run in opposite directions towards the upper and lower ends of the incision (Fig. 8.8). Because space under the retractor blades is usually limited, the final part of the incision can only be approximated with some interrupted 6-0 sutures with a 5/8 circular needle. Occasionally, inflammatory change has rendered the pelvic wall so brittle that only a loose approximation with some interrupted sutures can be achieved at all. In these cases, and whenever poor drainage is anticipated, an internal ureteric splint should be left in situ.

With significant perihilar scarring, intrasinusal dissection occasionally leaves a defect in the pelvic wall. Because of the risk of iatrogenic stricture of the pelviureteric junction, the temptation to close it under tension must be resisted. The defect is usually easily covered by a free graft of peritoneum loosely tacked on the defect with the shiny side inwards (Fig. 8.9) (Thüroff et al 1980). Peritoneum shrinks less than flaps raised from the fibrous capsule of the posterior surface of the kidney.

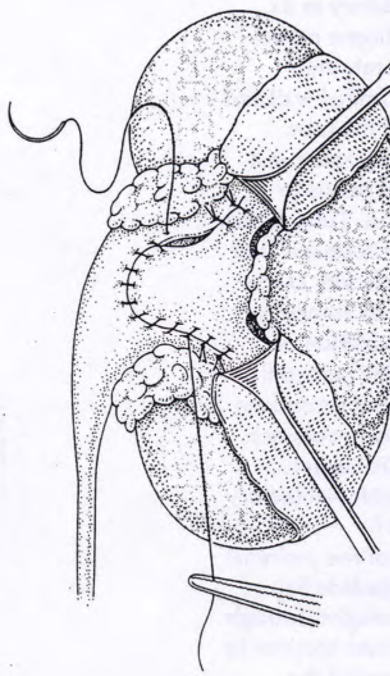


Fig. 8.8

Intrasinusal pyeloinfundibulotomy: closure of the collecting system.

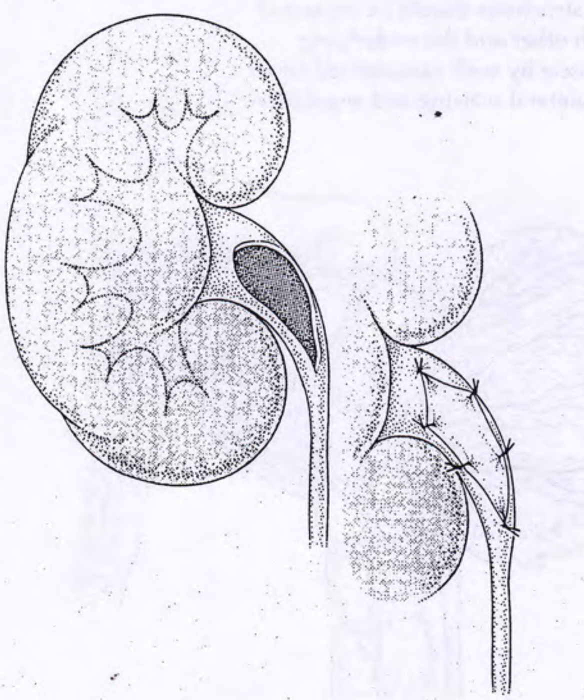


Fig. 8.9

Patching defects of the collecting system with a free graft of peritoneum.

After repositioning the kidney in its fascia, a soft 14 F–18 F silicone rubber tube is inserted via a separate stab incision through the abdominal wall and Gerota's fascia. The tip of the tube should be within this fascial space in a position dependent to the pelvis to prevent urinoma formation. Tube drains permit clean collection of drainage fluid well away from the wound and, in the author's experience, are not associated with an increase of extravasation or wound infection. To reduce perirenal scarring and to facilitate any secondary procedure that may become necessary at a later time, great care is taken to cover the entire kidney with viable fatty tissue. Where this cannot be accomplished by closure of the perirenal fat and Gerota's fascia, a pedicle flap of omentum is mobilized, brought through an incision in the peritoneum anterior to the colon and wrapped around the kidney (Turner-Warwick 1976). The most important region to cover is the area between the medial convexity of the lower pole and the ureter (Fig. 8.10). The two structures should be separated from each other and the underlying psoas muscle by well-vascularized fat to prevent ureteral scarring and angulation.

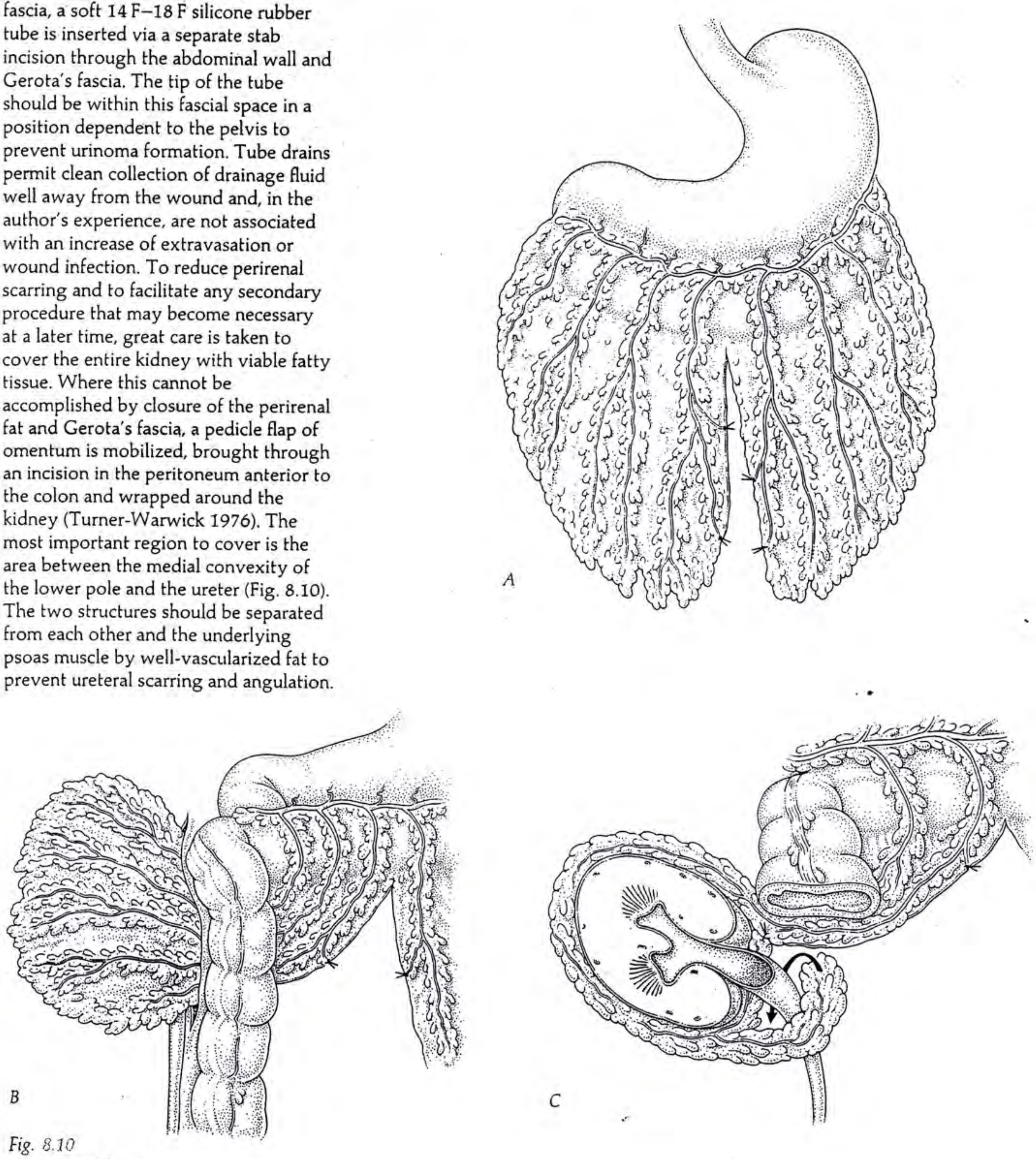


Fig. 8.10
(*A–C*) Omental wrap.

Coagulum pyelolithotomy

Frequently stones lie relatively mobile within the intrarenal portion of the collecting system, where they are difficult to palpate or to visualize despite good access to the collecting system as a whole. With the provision that the ratio of stone diameter:infundibulum permits transhilar extraction, strenuous intrarenal dissection may be avoided by trapping the calculi within a coagulum, which is extracted in toto with the calculi through a simple pyelotomy.

In central Europe the technique popularized by Patel (1973) is usually employed: 1 g of pooled human fibrinogen is dissolved in 20 ml saline. Two hundred units of thrombin are dissolved in 4 ml saline and both solutions are stored at 37°C for at least 15 minutes in a water bath. They are then rapidly mixed in a porcelain dish and injected within 30 seconds down a conical catheter into the collecting system. The ureter is first occluded with a rubber sling and all urine is evacuated from the pelvis. The amount of solution injected must not exceed the aspirated urine volume if overfilling of the collecting system and potential intravenous spillage is to be avoided. Within 5 minutes, the coagulum has solidified sufficiently for it to be removed with the stones it encases, via a standard pyelotomy.

In properly selected cases, the technique is highly satisfactory, especially as additional stones are often extracted which were not visible on preoperative films. For success, the technical details must be adhered to strictly and this renders the method tedious. In spite of numerous modifications, in particular to increase the tensile strength of the clot and to avoid the hepatitis risk by using autologous cryoprecipitated fibrinogen (Sonda et al 1986, Marberger 1986), coagulum pyelolithotomy has today virtually become obsolete. Stones suited for this approach are by far better managed by ESWL or percutaneous techniques.

NEPHROLITHOTOMY

Renal arteries are end arteries and any incision of the renal parenchyma leads to irreversible infarction of the parenchyma supplied by the divided vessels (Graves 1971). In 1882 Hyrtl demonstrated the relatively avascular plane between the parenchymal segments supplied by the anterior and posterior segmental arteries. For over half a century urologists bivalved kidneys along what they thought to be this plane to remove large renal calculi. The high rate of complications, in particular postoperative haemorrhage in up to 20%, and the need for secondary nephrectomy in up to 17% (Marberger 1981), provided the main arguments for conservative management of large asymptomatic staghorn stones.

The development of nephrolithotomy techniques along hypovascular intersegmental planes *defined individually* reversed the situation. By minimizing injury to intrarenal arteries the morbidity of the transparenchymal approach was decreased dramatically and surgical removal became the accepted treatment of all staghorn stones (Blandy & Marshall 1976).

Despite the excellent results achieved with anatrophic nephrotomy techniques, some nephrons are still damaged (Fitzpatrick et al 1980) and it remains the most invasive technique of removing renal stones. With the advent of extracorporeal shock wave lithotripsy and percutaneous stone manipulation, and the possibility of combining the two methods, the need was restricted to the exceptional case. For the sake of completeness the techniques are nevertheless still presented.

Radial nephrolithotomy

The second order branches of the renal artery, usually termed interlobar arteries, bifurcate at the base of each major calyx. They and their next order subdivisions take a strictly radial course in the interpapillary spaces to reach the cortex, where they form the arcuate arteries and finally become the afferent arterioles (Fig. 8.11). Basically, all arteries down to the fourth-order division of the renal artery have a more or less radial configuration. Arteries larger than fourth order divisions are not expected to be peripheral to the corticomedullary junction. A radial nephrotomy, extending from the peripheral convexity of the kidney inward directly onto the papilla, will therefore generally contact only third-order or fourth-order arterial branches, the larger of which course in the same direction as the nephrotomy (Wickham et al 1974, Wickham 1984, Marberger & Stackl 1986). With prudent blunt dissection, an ischaemic field, and the help of optical loupes, these vessels can usually be identified and swept out of the way without injury. Most of the dissection will be in the papilla, which is the least vascular part of the kidney. The large venous tributaries around the calyceal necks are also avoided.

Wickham (1984) has standardized this nephrotomy technique and termed it the radial-paravascular access to the collecting system. The kidney is completely mobilized and the pelvic portion and as much of the calyceal extensions as possible are removed by intrasinusal pyeloinfundibulotomy. The kidney is then suspended in a Netelast TM gauze sling formed from a Netelast TM bandage, size B, with a tape threaded as a drawstring through the mesh at one end; that end is slipped over the kidney and the drawstring is closed loosely around the pedicle and ureter so that the kidney is suspended and freely accessible from all sides. The residual stones are now precisely defined by intraoperative roentgenology (see p. 215) or intra-operative ultrasonography (see p. 218). Because the sonogram is capable of showing a true scale image of the stone, the calyx and the overlying parenchyma, it ultimately gives the optimal position for a nephrotomy (Alken 1986b). Whatever the technique used, it is most important that all calculi be localized as precisely as possible before the parenchyma is incised. Major intrarenal arteries can be identified with a standard Doppler stethoscope (Thüroff et al 1982). They are mapped out on the surface of the kidney and thereby avoided at nephrotomy. In kidneys with thin parenchyma second- and third-order branches may also be identified clearly. In kidneys with intact, well preserved parenchyma, deeper arteries, especially those from the contralateral segment, frequently limit the reliability of this method.

To obtain a bloodless field the renal artery is routinely clamped and the kidney cooled with slush ice (see p. 210). Since large hilar veins are not lacerated during radial nephrotomy, the renal vein need not to be occluded. With precise Doppler mapping of the intrarenal vessels and the use of modified nasal specula to compress minor transected vessels, radial nephrotomies can even be performed without interrupting renal circulation (Riedmiller et al 1981). Because blood oozing from the depth of the nephrotomy tends to obscure the field with this technique in kidneys with a thick parenchyma, it is more suitable for damaged kidneys with a thinned out cortex.

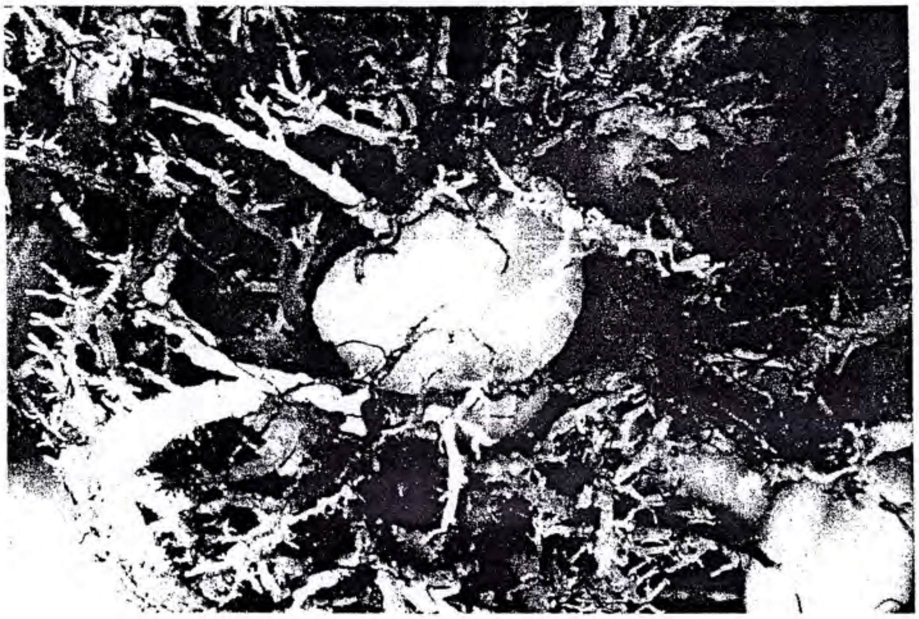


Fig. 8.11

Close-up of corrosion cast of anterior calyx of human kidney showing radial course of arteries and large venous tributaries around the calyceal infundibulum.

The fibrous capsule is incised with a scalpel in a radial direction over the stone. The renal parenchyma is then separated by blunt dissection, likewise in a strictly radial direction, using special dissectors developed for this purpose (see Fig. 8.4). The parenchyma is retracted with malleable spatulae, taking care not to tear the tissue by overzealous retraction. The collecting system is opened with the dissector or a pair of fine scissors and, if the nephrotomy was planned correctly, immediate contact should be made with the stone. The calyx is opened just wide enough to permit complete extraction of the stone. For this purpose the nephrotomy rarely needs to be longer than 1–2 cm (Fig. 8.12). The calyx is irrigated to remove debris and its neck is probed with a tube to ascertain free drainage. Occasionally stones in nearby minor calyces can also be removed through this incision. Use of small malleable sinus retractors (Fig. 8.4) facilitates deflection of the parenchymal bridge between the calyces and, with the help of laryngeal mirrors and a surgical headlight, other calyces can be inspected. However, no attempt should be made to extract calculi from an adjacent calyx if this requires incising the intercalyceal parenchyma, or forcing the stone through a narrow infundibulum. These stones are approached through a separate nephrotomy. With a complete staghorn calculus, every calyx may have to be opened through a separate nephrotomy and the basic principle of blunt dissection in a radial direction must always be followed.

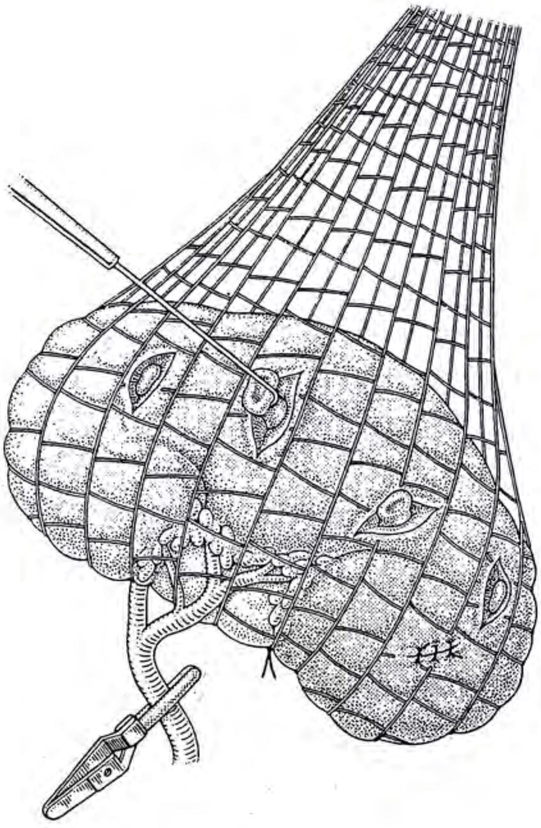


Fig. 8.12

Multiple radial nephrotomies; note clamped renal artery.

The nephrotomies are closed after all calculi are removed, as documented by an intraoperative roentgenogram. If peripheral arteries or veins were transected despite blunt dissection, they are carefully suture-ligated with 6-0 chromic catgut on a 5/8 needle in a special angulated needle holder. Closure of the collecting system is not attempted, since the minimal nephrotomy rarely offers enough space to accomplish this without tearing the mucosa. The nephrotomy is only closed with a running suture of the renal capsule using 5-0 chromic catgut. Although specific parenchymal sutures are not placed subcapsular haematomas are avoided if the most superficial layers of the cortex are grasped with the capsular suture. In general, this technique provides a reliable closure with virtually no postoperative haemorrhage or fistulae.

Where the fibrous capsule was inadvertently damaged during mobilization, the nephrotomy is closed with fibrin tissue adhesion. Fibrinogen cryoprecipitate (110 mg fibrinogen/ml) and cryoprecipitated bovine thrombin (500 NIH/ml) are dissolved in lactated Ringer's solution with a two-fold Ca^{++} ion content (40 mmol/l). All agents are commercially available in a prepackaged kit (Tissucol T M, Immuno, Vienna, Austria) for simple preparation. The two components, fibrinogen/aprotinin and thrombin/$CaCl_2$ are prepared during the initial phase of the surgical procedure and administered onto the parenchymal planes from separate syringes. This results in immediate polymerization with effective adhesive properties. After 3 minutes of firm compression, the nephrotomy is so tightly sealed that it cannot be reopened (Urlesberger 1979).

In addition, the nephrotomy closure can be reinforced with a patch of peritoneum or lyophilized collagen glued over the capsular defect. A 12 F nephrostomy tube is usually brought out through one of the nephrotomies. It not only provides reliable urinary drainage, but also permits accurate monitoring of the urine output and assessment of the collecting system by a simple nephrostogram in the postoperative period. The tube is tacked to the fibrous capsule with a single 4-0 catgut suture.

Both the early and late results of the paravascular radial nephrotomy technique are well documented and compare favourably with the results achieved with anatrophic nephrolithotomy. In 100 cases, Wickham et al (1974) reported no mortality, no fistulae, 4% postoperative haemorrhage and 9% residual calculi (Wickham 1984). A more recent update on 250 cases gives a similar complication rate. Permanent loss of renal function was not observed, not even in patients with solitary kidneys or in patients with severely compromised renal function. Technically the method is considerably simpler than anatrophic nephrolithotomy and the only situation where the latter appears superior is on the occasion where a large intrapelvic stone cannot be removed through a sinus approach (Marberger & Stackl 1986).

Anatrophic nephrolithotomy

The reason for the failure of longitudinal nephrotomy techniques along what was assumed to be 'Brödels avascular line' lies in the high variability of the vascular structures of the kidney. The intersegmental planes between the segments of the kidney supplied by each intersegmental artery are truly hypovascular, but they are highly variable and bear no predictable relationship to any residual fetal lobulations seen on the surface of the kidney (Boyce 1983). If they are to be utilized for surgical approach, the incision must follow their tortuous and angulated individual course. This requires precise definition of the planes by selective clamping of branches of the renal artery and mapping on the renal surface, where blood flow or no flow exists. Thermal gradients may be used for this, but visual demarcation by colouring the perfused segments as pioneered by Boyce (Boyce & Elkins 1974) has proven the most practicable technique. Combined with renal ischaemia, regional hypothermia and microsurgical techniques, renal damage is minimized in spite of extensive parenchymal incisions and reconstructive repair (Boyce 1983).

Boyce has standardized the surgical technique: using an intercostal approach, the kidney is completely mobilized and suspended on umbilical tapes. The renal artery is dissected and followed distally until the posterior segmental branch is isolated. In general, the intersegmental plane between the posterior segment supplied by this branch and the adjacent apical, basilar and anterior segments lie on the posterior side of the kidney, well off the convexity of the kidney. Following it downward to the collecting system, papillae supplied from two different segmental arteries may be split, but the entire collecting system can be exposed without severing third-order arteries. After the position of the stone is documented by intraoperative roentgenology, this plane is delineated precisely. Five minutes after administering 12.5 g mannitol intravenously, the posterior segmental artery is occluded with a soft bulldog clamp. Twenty millilitres of methylene blue are administered intravenously and the intersegmental plane is rapidly delineated by the change of colour between the blanched, ischaemic posterior segment and the bluish perfused part of the kidney (Fig. 8.13*A*). The line is marked on the capsular surface and the bulldog clamp removed again. If other intersegmental planes offer a better approach, as with some bifid collecting systems or stones in upper or lower pole calyces the procedure is repeated with other segmental arteries.

Once the anatomical landmarks are defined and the surgical strategy is decided upon, the renal artery is occluded with a bulldog clamp and the kidney is cooled with slush ice (Fig. 8.13*B*). Anatrophic nephrolithotomies have also been performed successfully by clamping some segmental arteries only (Namiki et al 1983, Zechner & Rummelhart 1984), but minor bleeding always tends to obscure vision and, in addition, the ischaemic segment of the kidney cannot be cooled properly. The fibrous capsule of the kidney is incised with the scalpel and the parenchyma is then bluntly separated until the pelvis or the calyx is entered. It is imperative that the intersegmental plane is precisely followed through all its convolutions and angles; if not too much time was lost between the injection of dye and clamping of the renal artery the plane is clearly visible by the junction of blue and pink tissue from capsule to pelvis (Fig. 8.13*C*).

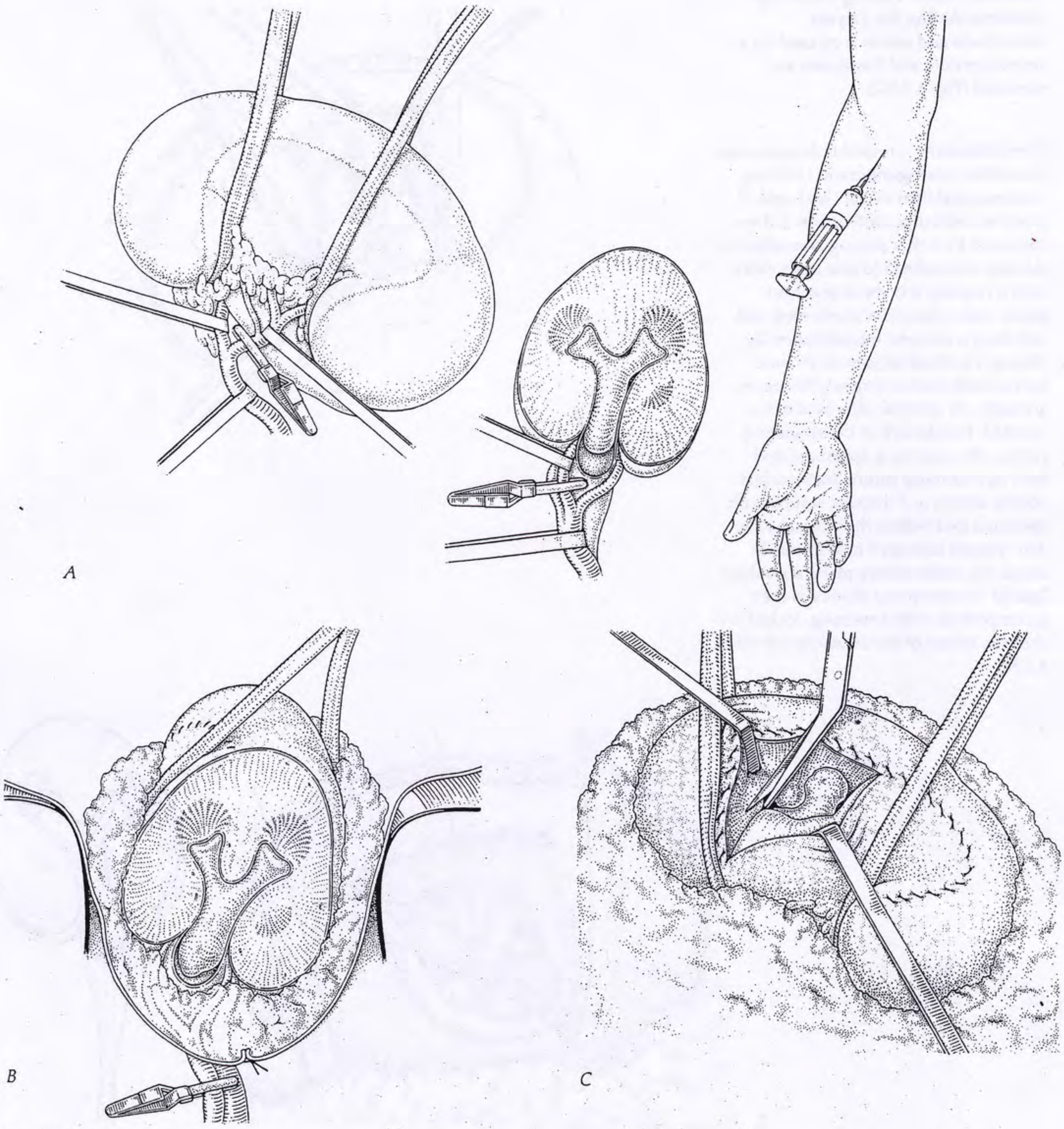
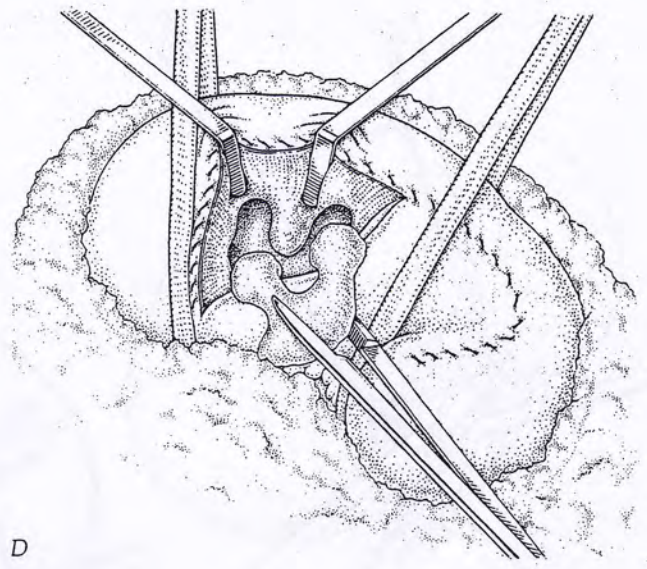


Fig. 8.13

Anatrophic nephrolithotomy: (*A*) defining the avascular plane between posterior and surrounding renal segments; (*B*) regional hypothermia with slush ice held around the kidney by a plastic bag; note clamped renal artery; (*C*) incision of the collecting system in extension of the avascular plane as marked on the surface of the kidney; (*D*) stone removal; (*E*) calicoplasty and closure of the nephrotomy with running sutures of the collecting system and renal capsule.

The entire stone-bearing collecting system including the calyces, infundibula and pelvis is opened by a single incision, and the stones are removed (Fig. 8.13*D*).

Complete stone removal is documented by another roentgenogram. Utilizing microsurgical instruments and optical loops infundibular obstruction is then corrected by either joining two adjacent stenotic infundibula to one large calyx with a running 6-0 chromic catgut suture (*calicoplasty*), or shortening and widening a stenotic infundibulum by closing a vertical incision at its base horizontally (*calicorrhaphy*). To secure drainage, an internal ureteral stent is inserted. For closure of the collecting system the mucosa is approximated with two running suture lines using a double-armed 6-0 chromic suture, with the knots tied within the parenchyma. Any vessels damaged inadvertently across the nephrotomy plane are suture ligated. Nephrotomy closure is then accomplished with a running, locked 4-0 chromic suture of the renal capsule (Fig. 8.13*E*).



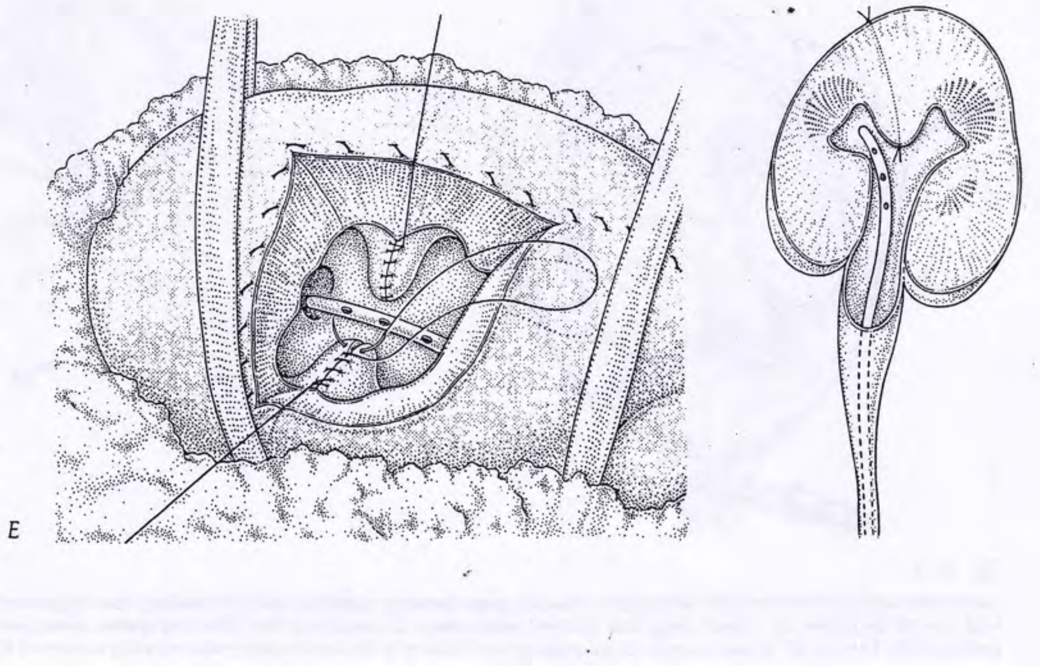


Fig. 8.13

The efficacy of anatrophic nephrolithotomy for removing even the most horrendous staghorn stone is well documented (Boyce & Elkins 1974, Boyce et al 1988, Resnick & Boyce 1980). The magnitude of the approach, however, is considerable and it frequently requires an operative time of more than 5 hours. Although the loss of renal function is minimized, in spite of prolonged renal ischaemia, the hyper-extended lateral position of the patient and regional hypothermia contribute to significant postoperative morbidity, in particular from pulmonary problems. If intrapelvic extensions of staghorn calculi can be extracted via the sinus, it is simpler and less traumatizing to remove the peripheral remnants through small radial nephrotomies.

RENAL ISCHAEMIA AND REGIONAL HYPOTHERMIA

Most nephrolithotomy techniques require a bloodless field and therefore temporary interruption of renal circulation. In general, this is achieved by occluding the renal artery with a soft arterial bulldog clamp with atraumatic arms. Since large hilar veins are not lacerated, the renal vein need not be occluded. Clamping the entire pedicle may appear to be more practical in severe perirenal fibrosis, but it has a higher risk of intimal damage to the renal artery, as well as the potential for incomplete arterial occlusion and slipping of the clamp. In addition, the impact of normothermic ischaemia on renal function is significantly more severe with complete pedicle occlusion than with clamping of the renal artery alone. Intermittent arterial occlusion with phases of recirculation likewise offers no advantage over continuous arterial occlusion in respect to ischaemic tolerance and wastes both blood and time (Marberger 1981). Manual compression of the renal vessels is absolutely unacceptable: ischaemia is usually incomplete, the assistant's hands impede the surgeon and intimal trauma may be just as severe as with poorly placed clamps.

In the normal kidney, normothermic ischaemia exceeding 30 minutes causes irreversible renal damage and pre-damaged kidneys are even more vulnerable (Rocca Rossetti 1983). Thus, warm ischaemia must be limited to a maximum of 15 minutes, a period sufficient for the removal of one or two well-localized calyceal calculi. For a more difficult nephrolithotomy, lengthy ischaemia will most likely be required and the kidney must be protected against ischaemic damage. Maximal diuresis at the time renal circulation is interrupted improves ischaemic tolerance. This is achieved by hydrating the patient with 1500 ml saline in the 12 hours preoperatively and maintaining full hydration throughout the procedure, as well as administering 0.2–0.4 mannitol/per kg/body weight intravenously, immediately before and after ischaemia. Normal microperfusion is thus restored more rapidly after ischaemia, and ischaemic bouts of up to 30 minutes are tolerated without significant damage (Oosterlink & De Sy 1983). Inosine, 30–60 mg, injected intra-arterially into the renal artery distal to the renal clamp, offers protection against normothermic ischaemia of up to 60 minutes duration (Fitzpatrick et al 1981). Most difficult nephrolithotomies, however, require a longer ischaemic period. Cooling of the kidney takes the time stress out of surgery in an ischaemic field, yet reliably prevents ischaemic damage.

Techniques for renal hypothermia include surface cooling, transarterial hypothermic perfusion and hypothermic irrigation of the collecting system. Their detailed descriptions are beyond the scope of this chapter and the interested reader is referred to the pertinent monographs (Marberger 1981, 1983).

Surface cooling with slush ice (Metzner & Boyce 1972) is the simplest and most universally applicable technique. Sterile slush is prepared by freezing standard saline packed in double-wrapped sterile vinyl bags. Vigorous shaking during the freezing process assures a soft consistency of the ice, but larger chunks may also be crushed on a side-table under a sterile cloth with an orthopaedic hammer. Immediately after the renal artery is clamped, a watertight dam is formed around the kidney with a standard intestinal bag such as that used for bowel surgery. Its blind end is cut open and the bag is placed over the kidney, so that the original open end with its integrated string-lace can be closed around the pedicle. The dam is filled with ice, so that only the immediate operative field remains exposed and the rest of the kidney is entirely covered (Fig. 8.13*B*). The operation is performed as usual, but throughout the procedure an assistant continuously removes dissolved slush with suction and replaces ice as needed to maintain the correct core temperature. In difficult nephrolithotomies requiring extended ischaemia, the core temperature is monitored with an electric needle thermometer. For optimal protection, core temperature of the kidney must be maintained between 10° and 20°C throughout the entire ischaemic period. If this is achieved, clamping of the renal artery is tolerated, without a permanent functional loss, for at least 3 hours (Ward 1975, Marberger & Eisenberger 1980, Boyce et al 1978). Properly performed, neither clamping of the renal artery nor renal cooling add significantly to the morbidity of renal surgery, so that the advantage of surgery in a bloodless field should be utilized generously.

INTRAOPERATIVE STONE LOCALIZATION

The surgeon must have facilities at hand to check the completeness of stone removal, to document this and to localize any retained fragments three dimensionally in order to reach them with minimal damage to the parenchyma. These conditions have medicolegal implications, and where they are not met open stone surgery should not be performed. Blind probing of the collecting system only is a totally inadequate method for this purpose.

Pyeloscopy

A variety of endoscopes have been developed for inspecting the collecting system of the kidney during open stone surgery. In contrast to percutaneous nephroscopes they are usually inserted through a pyelotomy and therefore termed pyeloscopes. Based on a suggestion by Leadbetter (1950), all rigid pyeloscopes commercially available today have an angled terminal extension that facilitates insertion of the instrument into the collecting system and reduces the chance of wound contamination from the surgeon's head. Endoscopes with 90° and 60° extensions 3–5 cm long are available (Fig. 8.14). Illumination and irrigation channels are integrated, but for extracting stones purpose-built forceps are attached to the instruments, or inserted through a detachable probe channel.

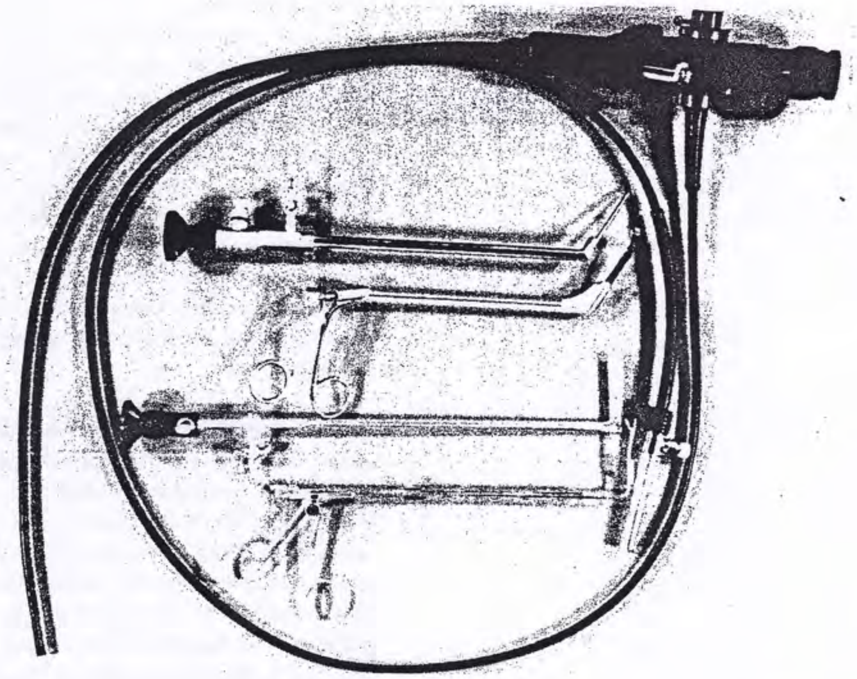


Fig. 8.14
Rigid pyeloscopes and stone forceps (top Wolf, bottom Storz) and 15 F flexible nephroscope (Olympus).

The instruments are used with perfusion from a bag of saline pressurized with a blood-pressure cuff inflated around the bag. The endoscope is inserted into the pelvis and advanced into the calyces under vision. The collecting system is then examined in a set pattern, an attempt being made to reach every papilla. With the standard posterior pyelotomy it is rarely a problem to enter anterior calyces, but with the acute angle between pelvis and posterior calyces the latter are frequently difficult to negotiate. This becomes even more difficult when the stone forceps are attached to the instrument. Where possible, stones are extracted with the forceps, but frequently the stone-bearing calyx can only be reached with the slender endoscope without the forceps. If it cannot be flushed from the calyx, the precise position of the stone is at least known and it can be retrieved with a slender stone forceps, or by a formal nephrotomy.

Flexible endoscopes, such as choledochoscopes or urethroscopes can also be used for pyeloscopy and they have been modified for the purpose. Their apparent main advantage, flexibility, has not proven too helpful. Even instruments with a 160° anterior and posterior deflection require considerable space for this movement and minor calyces are difficult to enter. Instruments 15 F in diameter, or thicker, have enough rigidity for directional manipulation with one hand, but it is difficult to insert them into slender calyces. Thinner instruments are too soft for this purpose and therefore difficult to guide; as they are usually ureteroscopes they are also too long for comfortable handling and require both hands of the surgeon on the instrument. These problems, combined with the expense, fragility and inferior optical quality in comparison to rod-lens systems, have prevented widespread use of intraoperative flexible nephroscopy.

The pyeloscope is a most helpful instrument to remove retained fragments from remote calyces. As an adjunct to extended pyelolithotomy the number of nephrotomies needed to remove peripheral stones can be reduced substantially by at least 60% (Alken 1986a). Even in the hands of the most experienced endoscopist, however, it is impossible to reach all papillae (Zingg & Futterlieb 1980, Mangin 1982). Pyeloscopy, therefore, has its merits in open stone surgery, but it does not obviate the need for intra-operative roentgenography.

Intraoperative roentgenography

Complete removal of all stones is essential for the success of every stone operation. Pyeloscopy does not permit reliable inspection of the entire collecting system and intraoperative ultrasound examination likewise has potential pitfalls. Moreover, neither technique permits documentation of the end result of the procedure, a potentially important medicolegal step. Intraoperative roentgenography, therefore, is mandatory whenever complete stone removal is not assured by visual inspection of the extracted calculus.

Fluoroscopy with a C-arm is unsatisfactory because of its poor resolution which is further reduced by overlying soft tissues, and because of the high radiation exposure (Rubenstein et al 1979). Good documentation is only obtained by contact films of the entire kidney (Boyce 1977). Even if the calculi are limited to one pole and a special roentgen unit with a finger-like anode is used (Renodor, Siemens FRG), adequate roentgenograms require a film—focus distance of at least 7 cm; even then they are difficult to read because of distortion and magnification (Eisenberger 1984). Gil-Vernet and Culla (1984) designed special film-holding forceps for positioning film around the renal pedicle, but they require special films and carriers which are difficult to obtain. It appears simpler to mobilize the kidney to some extent, that sterile film can be slipped behind it and can be exposed without interfering with the abdominal wall.

Standard nuclear medicine film (Kodak NMB), packed with a mammography film-intensifying screen and a 0.8 mm thick lead rubber shield in light-proof, plastic bags provides excellent resolution. The bags are loaded with the glossy (tube) side of the film facing the kidney and the dull (emulsion) side facing the screen, with the lead shield on the side of the screen (Marberger & Hruby 1984). The film is cut to 18/12 cm or 9/12 cm. With the wound held open by the retractor, the film is placed behind the kidney. Kidney and film are held in position by clamping the Netelast bandage used to hold the kidney to the film. A standard portable X-ray machine with a light pointer is then focused on the kidney with a film-focus distance of 70 cm (Fig. 8.15). As the exposure situation does not vary, the same exposure time and energy level can be applied again once it has been determined empirically; in general it is around 0.8 seconds and 60 kV. Of course, commercially available kidney films (Kodak X-Omat KS film) sealed in flexible plastic bags and contoured to the shape of the kidney can be used as an alternative. As they do not contain an intensifying screen, they need higher exposure time. The notch designated for the renal pedicle may also obscure a large segment of the kidney.

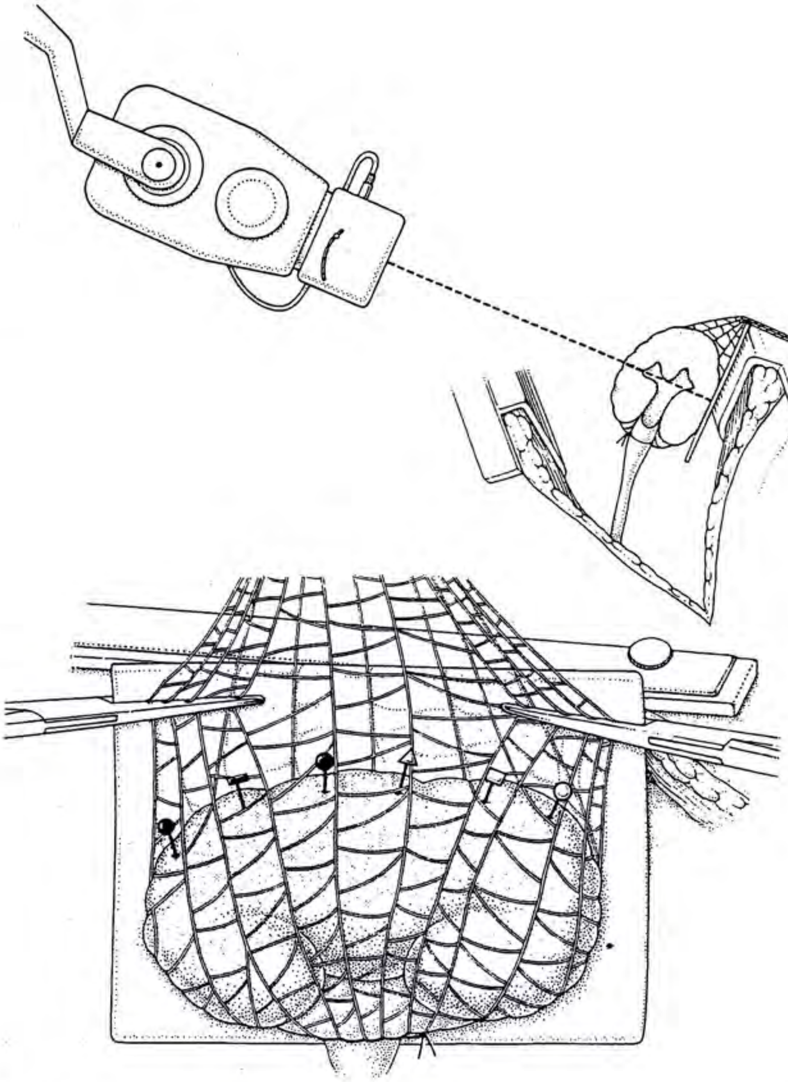


Fig. 8.15
Intraoperative roentgenography.

If the purpose of the film is only to document complete stone removal, one film of the entire kidney in the frontal plane suffices. Retained stones are localized three-dimensionally with an additional film in a second plane, preferably in a 90° angle to the first. This is achieved by slipping the smaller size film under the lower or upper pole, tilting the kidney out of the wound with the Netelast support and by directing the X-ray beam along the longitudinal axis of the kidney. The film depicts an almost transverse cut of the kidney that permits precise localization of the stone in an anterior or posterior calyx. For orientation on the film, marking needles with different heads are inserted into the kidney along the coronal and transverse planes. Films are repeated as needed until the kidney is definitely stone free (Fig. 8.16).

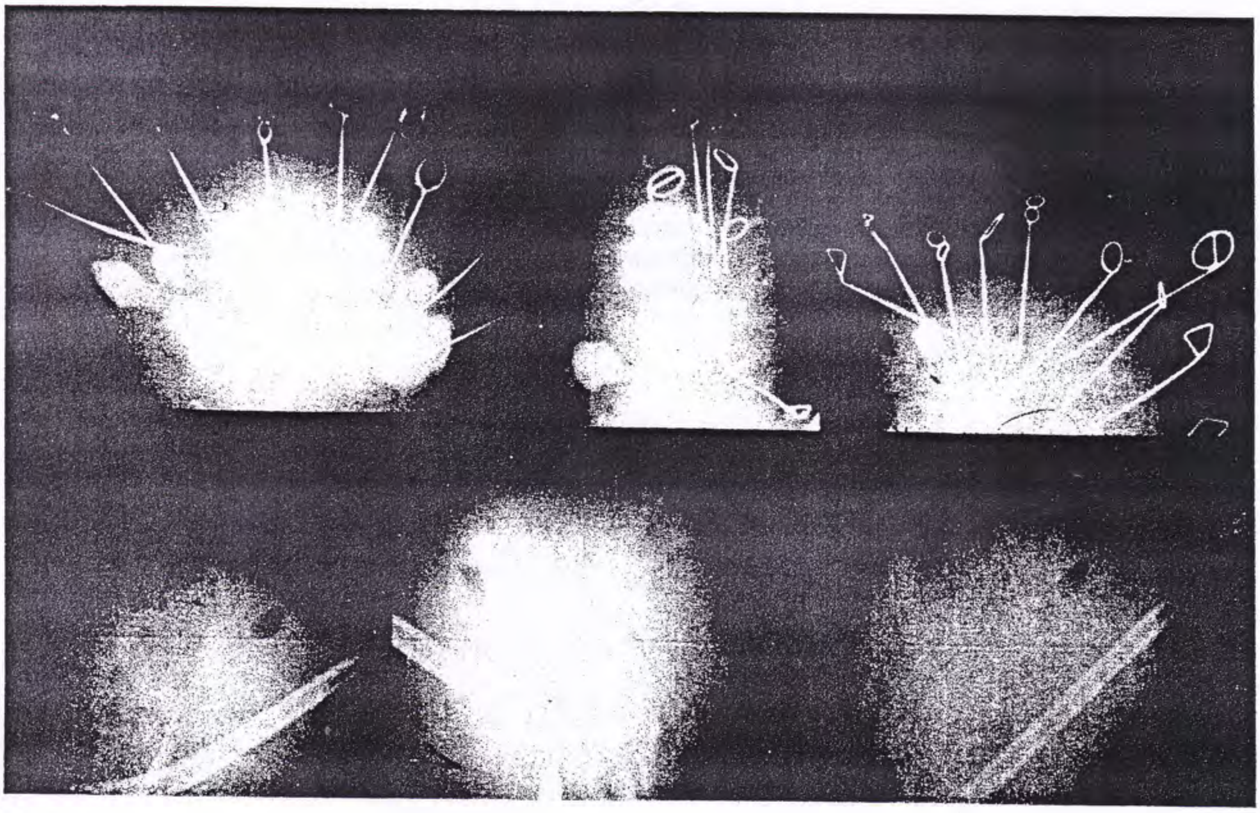


Fig. 8.16

Intraoperative contact radiographs obtained before stone removal in the frontal plane and transverse planes of the upper and lower poles; localization of a small central residual fragment and documentation of complete stone removal.

Intraoperative ultrasonography

Stones can be localized three-dimensionally by B-mode ultrasonography of the exposed kidney, provided that the transducer is sterile, small enough to be handled on the renal surface and that it permits imaging to a maximum depth of 5 cm. Ophthalmologic real-time scanners operating in the range of 7.5–10.5 MHz can be utilized for this purpose and some specifically modified instruments are available (Lytton 1983, Alken 1986b). With some practice, calculi with diameters as small as 2 mm can be identified clearly by their high echo-intensity and the echo-shadow behind them. Air bubbles, intraparenchymal scars and signal amplification from obstructed calyces very close to the surface of the kidney may be misinterpreted as stones, but sequential scanning from various angles reduces the error rate. Because the sonogram is capable of showing a true scale image of the stone, the calyx, the overlying parenchyma and even some of the intrarenal vessels, it facilitates choosing the perfect position for a nephrotomy. A needle can be directed to the stone under ultrasonic guidance to delineate the direction of the incision (Fig. 8.17). If, in addition, the intrarenal arteries are mapped out with a Doppler probe the paravascular radial approach is optimized.

At the present time, the main limitation of intraoperative ultrasonography comes from the limited availability of proper equipment. With open stone surgery becoming rare, only a few institutions will procure transducers specifically designed for this purpose. In general, instruments already available for other purposes have to be used and they rarely fulfil the requirements in sterility, size and a frequency > 7.5 MHz. Transducers of this type only permit examination of a small segment of the kidney and cannot be utilized for proving complete stone removal.

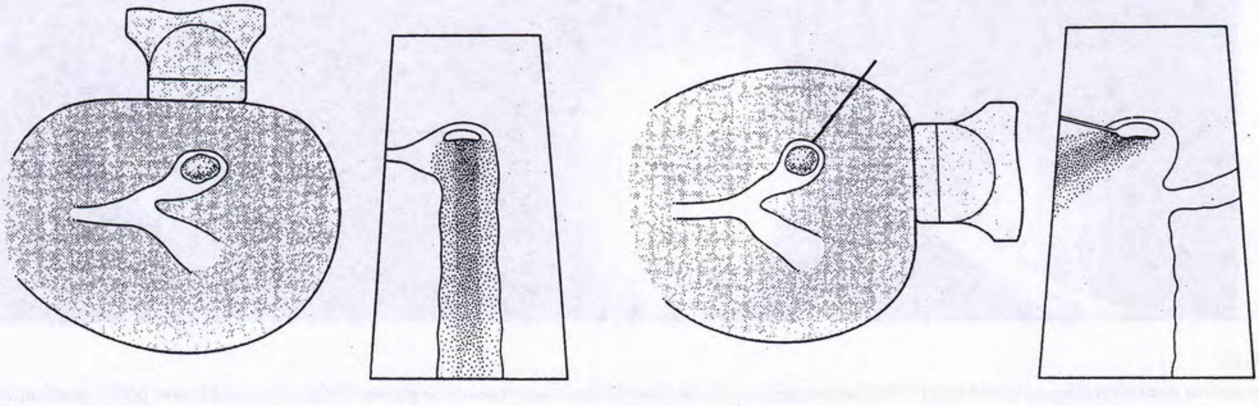


Fig. 8.17

Ultrasonic localization of a calyceal stone (after Alken 1986b).

STONES AND OUTFLOW OBSTRUCTION

Where drainage problems exist related to abnormalities apart from a stone, surgical correction of the obstruction appears to be a logical addition to stone removal, if recurrent stone formation is to be prevented. This, however, is a rather rare condition. A narrow ureteropelvic junction is frequently observed on the excretory urogram in the presence of symptomatic pelvic stones, but it is reactive and invariably normalizes without further measures after stone removal. Obstruction is a more common problem after open stone surgery as a result of periureteral scarring, but the higher complication rate of secondary procedures warrants a more cautious approach to reconstructive surgery. In many situations with relative obstruction, percutaneous removal of the stone and correction of any other factors contributing to stone formation may already eliminate the problem at significantly less morbidity. With endourological techniques, such as percutaneous pyelolysis or balloon dilatation, at least 60% of secondary strictures at the ureteropelvic junction or at ureterointestinal anastomoses can be managed without open surgery (Korth & Kunkel 1987, Kramolowsky & Clayman 1988). Where these techniques fail, and in situations where stone formation is obviously secondary to outflow obstruction, corrective surgery is unavoidable. This may originate at any level of the collecting system, frequently in combination with chronic urinary infection. This presentation is limited to situations where the reconstructive procedure can be combined with stone removal through one incision.

Relative obstruction at the level of the calyceal infundibula is common and the main reason for the high rate of retained fragments after ESWL of calyceal stones. The problem becomes most obvious with stones in *calyceal diverticula*, where the communicating channel to the collecting system is so delicate that even minute fragments will not pass. Most symptomatic diverticula can be cleared of stones percutaneously and the channel draining into the collecting system may even be enlarged, or the diverticulum may be obliterated endoscopically (Hedelin et al 1988, Hulbert et al 1988). Only rarely is open surgical intervention indicated, mainly for persistent infection. The diverticulum is opened through the thinned-out parenchyma over it, the stones are removed and the infundibulum is corrected by calicorrhaphy. Multiple *strictured calyceal infundibula* have to be approached by anatrophic nephrolithotomy for intrarenal repair.

Although the lower pole calyces appear to have a sump effect that promotes stone growth and collection, precise follow-up studies have shown that the rate of stone recurrence is not influenced by *lower pole partial nephrectomy* (Myrvold & Fridjofsson 1971, Wald et al 1978, Bates et al 1981, Thimoney et al 1988). In view of loss of at least one-third of the parenchyma of the kidney, partial nephrectomy is no longer justified purely on a prophylactic basis, or to facilitate stone removal, regardless of the technique used. If the parenchyma of the lower pole is destroyed, so that the lower pole calyces form a large dependent sack, correction of the drainage situation may be justified in selected cases. A modified *inferior pyelonephrolithotomy* usually gives better results than a lower pole guillotine resection. The intersegmental plane between posterior and basilar segment is delineated and a pyelotomy is extended into the parenchyma along this plane until the lowest point of the calyx is reached. With correct patient selection, i.e. a kidney with extremely thin parenchyma, there is little haemorrhage from the severed parenchyma, which can be controlled by a running suture. After complete stone removal the pyelotomy is extended over the ureteropelvic junction down the ureter to a point opposite to the lowest point of the basilar calyx. By approximating the opposing incision lines of the renal collecting system and ureter with running 5-0 chromic catgut sutures, the ureteropelvic junction is lowered to drain the lower pole calyces. Alternatively, all of the lower pole calyces but a flap of urothelium are excised; the latter is interposed in the incision of the ureteropelvic junction to form a funnel (Rocca Rossetti 1984).

Uncomplicated stones in the presence of *congenital uretero-pelvic obstruction* are usually best managed by standard *pyeloplasty* and transhilar stone extraction (Fig. 8.18). With success rates over 90%, reconstructive surgery has significantly better results than *percutaneous* pyelolysis, obviously because the redundant collecting system is also reduced (Korth & Kunkel 1986). The success rate drops rapidly if the collecting system is scarred by previous surgery or severe inflammation. Percutaneous techniques are preferred in this situation and open surgery is only resorted to when they fail. With complete mobilization of the kidney to bring the collecting system closer to the ureter, a dependent, funnel-shaped anastomosis can usually be achieved with healthy tissues. It is stented and the kidney is also drained with a nephrostomy. Finally, kidney and proximal ureter are wrapped with healthy omentum.

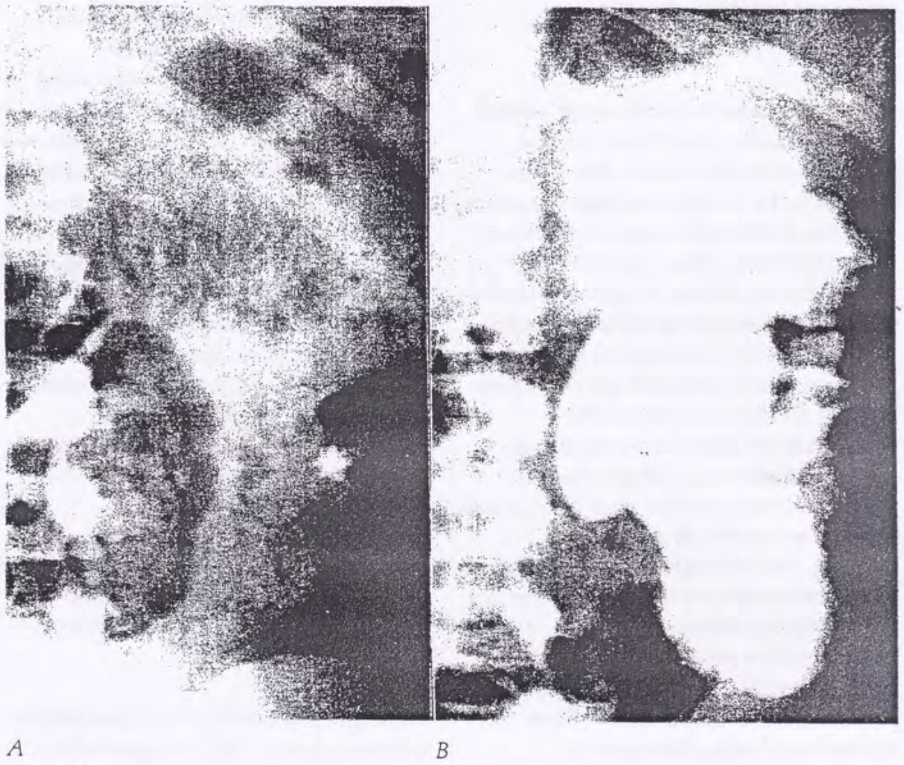


Fig. 8.18

Hydronephrosis caused by aberrant vessel at the ureteropelvic junction and peripheral calyceal stone in 10-year-old girl (plain film *A* and excretory urogram *B*).

If this fails, or the pelvis proves to be too scarred for a tension-free anastomosis, a *ureterocalicostomy* can be performed. The key to success of this procedure is an extremely thinned out lower pole parenchyma and a wide, watertight anastomosis between calyx and ureter, reinforced with fibrous capsule (Fig. 8.19). If the lower pole parenchyma is still well preserved, a formal lower pole partial nephrectomy is essential but the late results still remain poor (Brecht & Zingg 1982). Alternatively, the entire ureter is *substituted with ileum*. Adequate renal function to compensate the hyperchloremic acidosis resulting from the absorptive potential of the bowel segment is an essential prerequisite for this decision. A loop of about 25 cm of ileum is isolated where it has the most mobile mesentery, and it is passed through the mesocolon of the ascending or descending colon into the retroperitoneal space (see Fig. 8.23). After removing all scar tissue, its upper end is anastomosed directly to the remnants of the renal pelvis or even to the calyces.

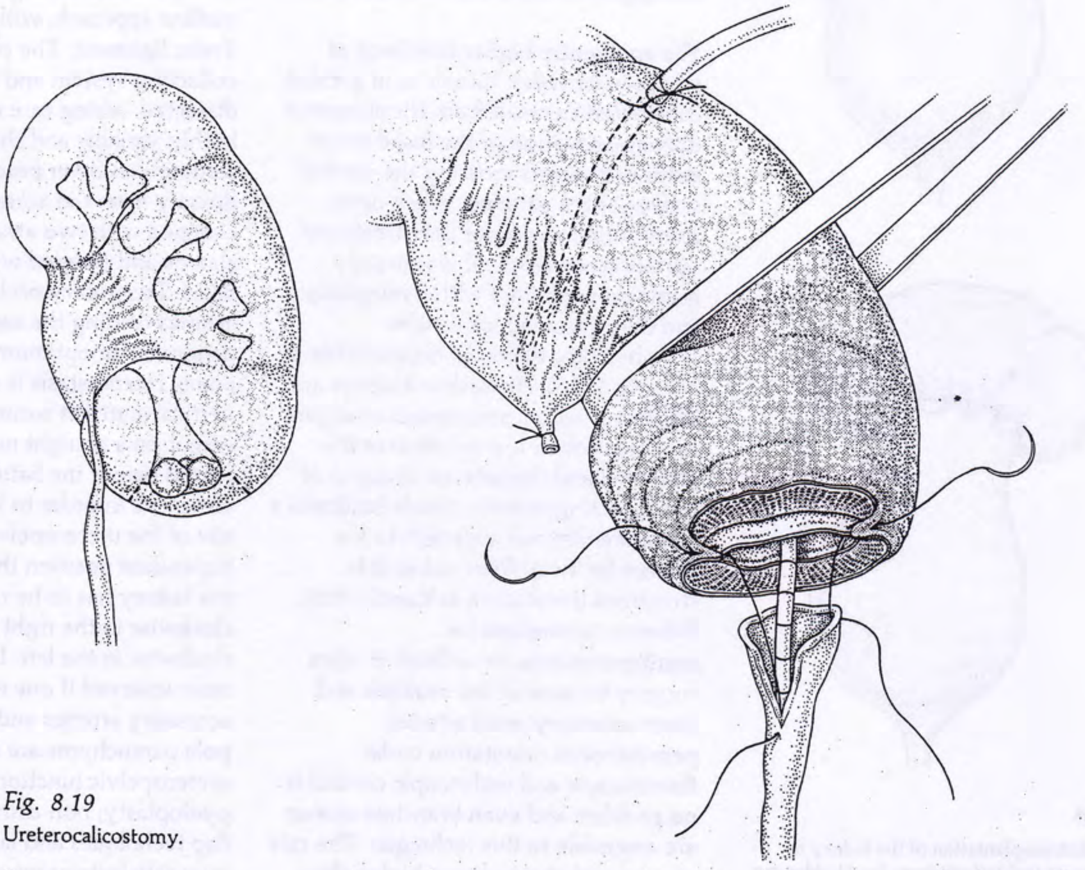


Fig. 8.19

Ureterocalicostomy.

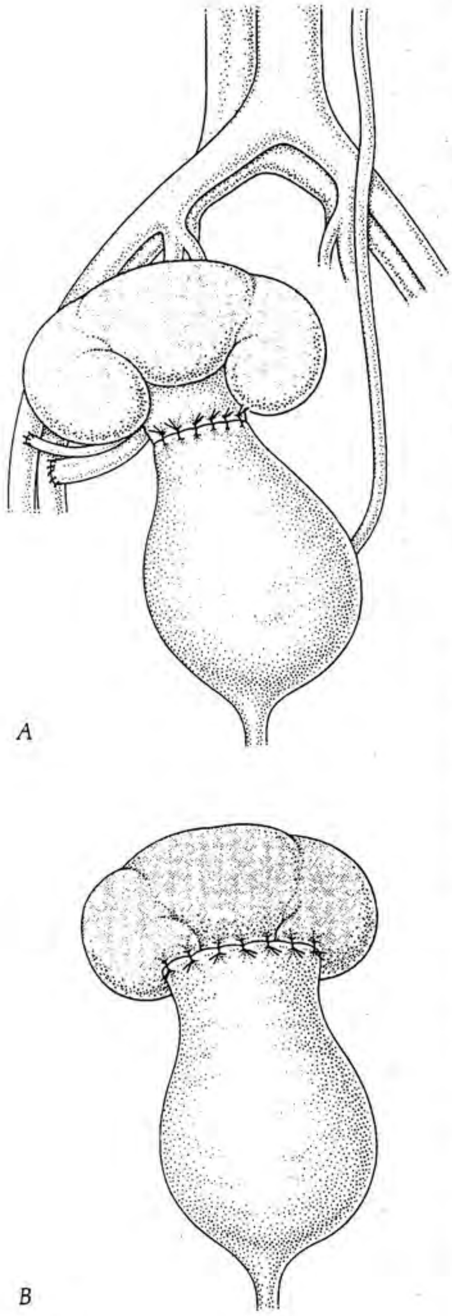


Fig. 8.20

(*A, B*) Autotransplantation of the kidney to bridge severe ureteral stricture; the bladder can be anastomosed to the remnants of the renal pelvis or directly to the intrarenal collecting system and renal capsule.

The distal end is anastomosed to the dome of the bladder without any attempt to prevent reflux (Boxer et al 1978). The drainage problem can, of course, also be corrected by *autotransplantation* of the kidney to the iliac fossa and direct pyelovesicostomy (Pettersson et al 1980). Stone bearing kidneys with obstruction of this type are usually chronically infected and their vascular pedicle tends to be encased in scar tissue from previous surgery, so that the risk of vascular complications after autotransplantation is higher for this group than for other indications (Bodie et al 1986). As all renal stones can be removed by in-situ techniques, this approach should be the last choice.

The apparently higher incidence of stones in *horseshoe kidneys* is, in general, considered to result from the abnormal drainage situation of the fused lower poles and ureters crossing the ventral surface of the isthmus. When open stone surgery was the only treatment option, stone removal was usually routinely combined with pyeloplasty and only the need for routine symphysiotomy was at debate (Pitts & Muecke 1975). Horseshoe kidneys are ideally suited for percutaneous surgery because of their low position in the abdomen and the anterior location of the collecting system, which facilitates a transparenchymal approach to the calyces far away from vulnerable structures (Janetschek & Kunzl 1988). Whereas intraoperative roentgenograms are difficult in open surgery because of the multiple and short accessory renal arteries, percutaneous orientation under fluoroscopic and endoscopic control is no problem and even branched stones are amenable to this technique. The rate of recurrent stones is not higher than that after open surgery and in fact the high recurrence rate observed after previous treatment strategies was certainly in part also related to perirenal and ureteral scarring. Today open surgery is only indicated in the presence of definite outflow obstruction at the level of the ureteropelvic junction, as documented by a positive diuresis renogram. It usually coincides with a high ureteral insertion, a redundant collecting system and a narrow or even stenotic preisthmic ureter.

This situation requires symphysiotomy, repair of the ureteropelvic junction, lateral rotation of the kidney and nephropexy. With unilateral hydronephrosis, an extraperitoneal approach via a 12th rib supracostal incision carried anteriorly is usually chosen. If obstruction is bilateral, it can be repaired in one session through a transperitoneal midline approach, with incision of the Treitz ligament. The obstructed collecting system and isthmus are dissected, taking care not to injure the highly variable and short arteries feeding the lower pole and originating directly from the aorta. The isthmus is clamped with two atraumatic Satinsky clamps and severed with a scalpel (Fig. 8.21). Temporary occlusion of the arteries feeding the segment may delineate the optimum intersegmental plane. Haemostasis is accomplished with vertical mattress sutures of 0 chromic catgut on a straight needle, which are placed before the Satinsky clamps are removed. In order to bring the future site of the ureteropelvic junction into a dependent position the lower pole of the kidney has to be rotated outwards; clockwise in the right side and counterclockwise in the left. In general, this is only achieved if one or two of the accessory arteries and the related lower pole parenchyma are sacrificed. The ureteropelvic junction is corrected by pyeloplasty; non-dismembered spiral flap techniques and lateral nephropexy give satisfactory results (Pitts & Muecke 1975, De Weerd 1979).

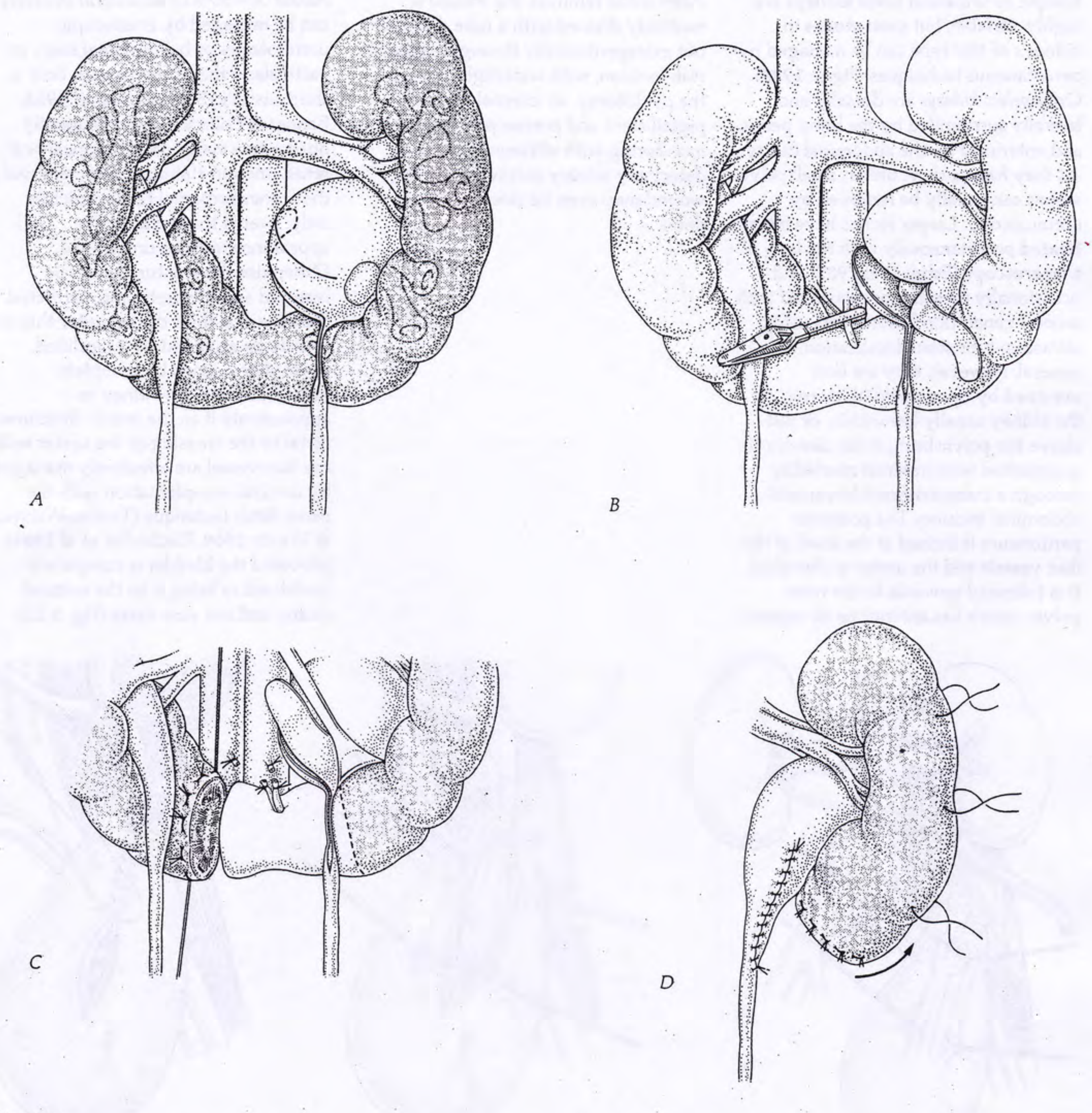


Fig. 8.21
(*A–D*) Horseshoe kidney: stone removal and correction of outflow obstruction by symphysiotomy, pyeloplasty and lateral rotation of the kidney.

Ectopic or unilateral fused kidneys are highly variable, but most stones in kidneys of this type can be managed by percutaneous techniques (Figge 1988). Only *pelvic kidneys* are dorsally and laterally surrounded by the bony pelvis and anteriorly by the abdominal cavity. As they have a short ureter, small pelvic stones can usually be removed by ureteroscopy. Larger stones have been treated percutaneously with the help of a laparoscope (Eshgi et al 1985) and occasionally they can be visualized with second generation lithotriptors using ultrasound for stone localization. In general, however, they are best removed by open pyelolithotomy. As the kidney usually lies within, or just above the pelvic brim, it can directly be approached with minimal morbidity through a transperitoneal lower mid-abdominal incision. The posterior peritoneum is incised at the level of the iliac vessels and the ureter is identified. It is followed upwards to the renal pelvis, which lies anterior to all vessels.

After stone removal, the wound is routinely drained with a tube drain led out extraperitoneally through a separate stab incision; with watertight closure of the pyelotomy, an internal double-pigtail stent and precise postoperative monitoring with ultrasonography to detect any urinary extravasation the wound may even be closed without drain.

About 30–50% of all *ureteral strictures* can be managed by endoscopic ureterotomy or balloon dilatation, in particular if they present with only a short history (Silverstein et al 1988, Banner & Pollack 1984). Frequently obstructive symptoms disappear and renal function stabilizes with removal of the stones proximal to the stricture only, even if the radiographic appearance remains unchanged. Otherwise the stricture has to be resected and the ureter reconstructed. In the proximal third of the ureter this can usually be achieved by a modified pyeloplasty, aided by complete mobilization of the kidney to approximate it to the ureter. Strictures distal to the crossing of the ureter with the iliac vessel are effectively managed by ureteral reimplantation with the psoas hitch technique (Turner-Warwick & Worth 1969, Riedmiller et al 1984), provided the bladder is completely mobilized to bring it to the ureteral stump and not vice-versa (Fig. 8.22).

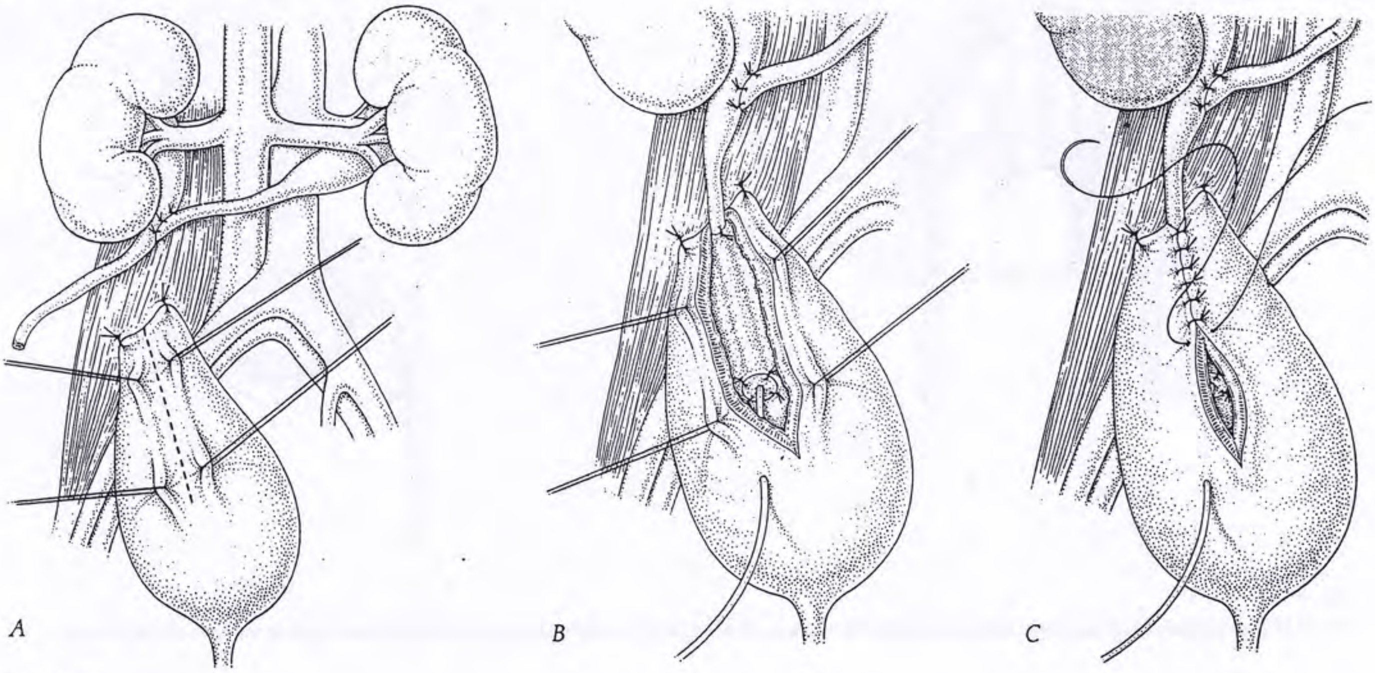


Fig. 8.22

(*A–C*) Ureteral reimplantation with psoas hitch technique, here combined with transuretero-ureterostomy because of bilateral strictures of the distal ureters; note that bladder is opened to the level of fixation on the psoas and that ureter enters submucosal tunnel at this point.

The technique can be combined with a Boari flap to substitute the entire distal half of the ureter (Fig. 8.23) (Olson 1983). Some short mid-ureteral strictures can be repaired by ureteroureterostomy, especially if the segment proximal to the stricture was tortuous and dilated. Otherwise the ureter has to be replaced by ileum, either totally or in combination with a psoas-bladder hitch (Fig. 8.24). Precise debridement of all scar tissue, spatulation of both ureteral ends, a watertight anastomosis with interrupted 5-0 chromic catgut, ureteral stenting and nephrostomy drainage are the keys to success. Occasionally the problem may also be solved by transuretero-ureterostomy (Peorse et al 1985).

Vesical and urethral calculi always result from infravesical obstruction, the insertion of foreign bodies or functional disorders. Elimination of the reason for stone formation is therefore an integrated part of stone treatment.

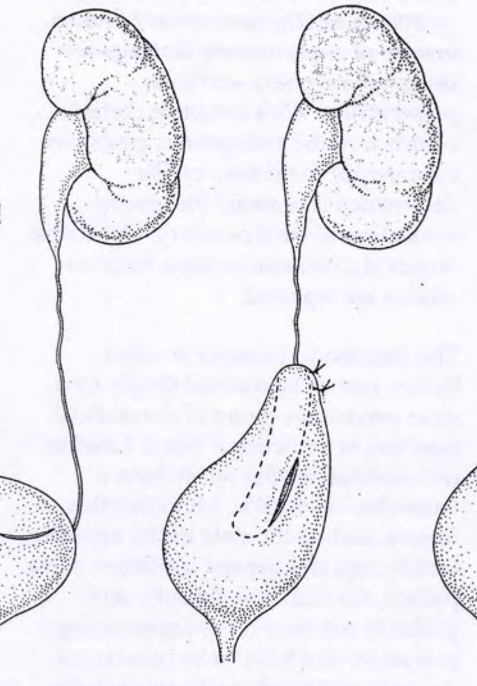
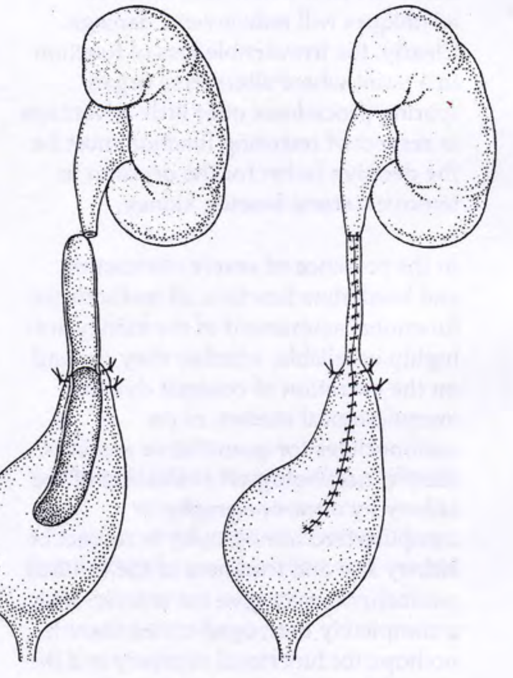


Fig. 8.23
Replacement of mid-ureter by combined psoas hitch and Boari technique.



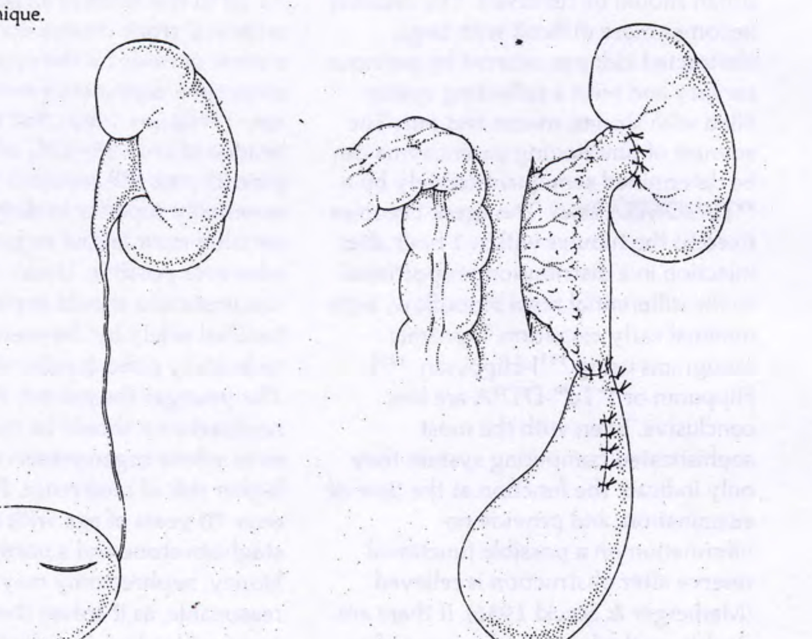


Fig. 8.24
Replacement of the ureter with ileum and psoas hitch.

NEPHRECTOMY

Ablative surgery has become the type of open stone surgery being performed most commonly, although it will hopefully be needed less frequently in the future as the new, less invasive techniques will reduce renal damage. Clearly, the irreversible loss of function to a point where alternative organ-sparing procedures offer little advantage in respect of restoring function must be the decisive factor for the decision to remove a stone-bearing kidney.

In the presence of severe obstruction and borderline function, all methods for functional assessment of the kidney are highly unreliable, whether they depend on the excretion of contrast dye for morphological studies, or on radionuclides for quantitative analyses. Simple morphological evaluation of the kidney by ultrasonography or computerized tomography in respect of kidney size and thickness of the residual parenchyma may give the answer; with a completely destroyed cortex there is no hope for functional recovery and the organ should be removed. The decision becomes more difficult with large, obstructed kidneys, scarred by previous surgery and with a collecting system filled with stones, mucus and pus. The amount of functioning parenchyma can be determined semiquantitatively by a ^{99}Tc^{m}-DMSA scan. The agent becomes fixed to the tubules within 1 hour after injection in a distribution proportional to the differential renal bloodflow, with minimal early excretion. Dynamic renograms using ^{131}I-Hippuran, ^{123}I-Hippuran or ^{99}Tc^{m}-DTPA are less conclusive. Even with the most sophisticated computing system they only indicate the function at the time of examination, and provide no information on a possible functional reserve after obstruction is relieved (Marberger & Stackl 1986). If there are doubts on the functional reserve of an obstructed kidney of borderline function, functional assessment should be repeated after the kidney is drained by percutaneous nephrostomy for several days. Already the amount of urine produced and its specific gravity provide valuable information; in an adult, an infected kidney producing $<$ 500 ml isosthenuric urine/24 hours, in spite of nephrostomy drainage for several days, rarely warrants preservation. With complete ureteric obstruction the endogenous creatinine clearance of the kidney can be determined repeatedly for precise evaluation of renal recovery. Otherwise, standard split radio-isotope function studies are repeated.

The decision to preserve an adult kidney cannot be reached simply by a strict percentage figure of the residual function, in particular if this is based on radioisotope studies which have a variability of ± 10%. Multiple other factors, such as the state of the opposite kidney, age and general condition of the patient, the technical difficulty and probable outcome of an organ-saving procedure also have to be considered. As up to one-third of all patients with unilateral stone disease may experience a stone episode on the opposite side at some time during their remaining life-time (Williams 1963), and since a residue of only 15–20% of the normal parenchyma still provides renal function essentially superior to dialysis, the decision must favour organ preservation wherever possible. Under no circumstances should nephrectomy be justified solely by the presence of technically difficult recurrent stones. The younger the patient, the less nephrectomy should be resorted to, even where organ preservation carries a higher risk of recurrence. For patients over 70 years of age with a complete staghorn stone and a normal opposite kidney, nephrectomy may be more reasonable, as it solves the problems for years with a low complication rate. The main indication for nephrectomy in urolithiasis remains pyonephrosis, i.e. an organ completely destroyed by suppurating infection. Again, a percutaneous nephrostomy solves most emergency situations and may ultimately save the kidney.

Whereas removal of a kidney destroyed by chronic obstruction without inflammatory alterations is a simple procedure, the same operation may be made extremely difficult by perirenal scarring, especially after previous surgery. The kidney is approached as outlined on page 200. It is most important to carry out the dissection along the fibrous capsule, in particular at the medial aspect of the upper pole. If this plane is lost, the duodenum, vena cava and adrenal gland may be lacerated on the right and the spleen and adrenal gland on the left. Subcapsular dissection should be avoided. If it occurs, the capsule should not be stripped off the kidney around the renal pedicle to avoid laceration of the renal vein. As soon as the kidney is mobilized so that it only remains attached at the renal pedicle, but the sutures in the pedicle are still concealed within fibrous tissue, the renal capsule is incised from its inner aspect in the assumed direction of the vessels. The vessels are then dissected out step by step, if necessary after identification with a Doppler probe. Dissection is commenced on the posterior aspect of the pedicle and directed at the renal artery first. After the artery is double-ligated the veins are isolated and ligated. The ureter is ligated and severed below any obstruction, i.e. in a non-dilated segment. If this is impossible because of distal obstruction, a hemovac drain should be inserted into the dilated segment of the ureter and be secured in place with a catgut suture for 48 hours. With significant infection, the wound is drained with two large tube drains led out through the wound, rather than through separate stab incisions; it is closed in one layer with large through-and-through sutures.

POSTOPERATIVE CARE AND COMPLICATIONS AFTER STONE SURGERY

In the immediate postoperative period, elderly patients with compromised *pulmonary function* may experience some respiratory problems after renal surgery. Due to the intraoperative lateral decubitus position, the contralateral lung is poorly ventilated and basal atelectasis is often observed postoperatively. If the pleura was opened, a chest roentgenogram should be obtained immediately after the operation to rule out a pneumothorax, even if the defect appeared to have been repaired successfully. When renal ischaemia and regional hypothermia are utilized over several hours, this may cause significant total body cooling (Birch & Mims 1975). By containing the slush within the operative field with a tightly sealed dam, prewarming all intravenous fluids, and using electric warming pads or thermistor-controlled heat-strips, depression of the core temperature can usually be prevented. As an adjunct, the patient's legs are wrapped preoperatively with cotton wadding covered by aluminium foil. The patient is well hydrated in the postoperative phase and urinary output is monitored carefully. A blood–gas analysis and haematocrit measurement are obtained routinely 1 hour postoperatively. Blood–gas imbalances must be corrected immediately and any significant blood loss is replaced. In patients with borderline renal function, the central venous pressure and peripheral arterial pressure are monitored continuously to optimize fluid management.

Although rare, *haemorrhage* continues to be the most important postoperative complication. Significant bleeding from the nephrostomy at the end of the operation is an ominous sign, but usually severe haemorrhage rapidly clogs the narrow tube and intrarenal haemorrhage is thereafter mainly vented into the collecting system. After more extensive nephrolithotomies, a urethral catheter is left in place for 24 hours both to monitor urinary output and to detect severe haematuria, which may otherwise cause unnoticed clot retention. Haemorrhage is usually of venous origin and most often will cease spontaneously within 24–48 hours. Epsilon-aminocaproic acid should not be administered, since it promotes clot formation and may precipitate ureteral and urethral obstruction. When massive bleeding is of arterial origin, expectant management is futile. It mainly occurs after parenchymal incisions, and only rarely after a pyelotomy, from unnoticed damage to a segmental artery during sinus dissection. Just as with haemorrhage after percutaneous nephrolithotomy, the treatment of choice in this situation is superselective transarterial angioinfarction with autologous clot material, gelfoam or Gianturco coils. Angiographic techniques permit precise localization of the arterial lesion and selective occlusion (Marberger & Günther 1984). At surgical re-exploration, the bleeding vessel can rarely be identified within the haematoma and the procedure may end with a nephrectomy.

Even with ischaemic hypothermia, poorly functioning kidneys may show a transient postoperative decrease in function (Marberger & Eisenberger 1980). Nephrotoxic agents, in particular nephrotoxic antibiotics, should be avoided. If the preoperative culture and sensitivity testing permits no alternative, the dosage administered must be based on daily determinations of creatinine clearance or the serum levels of the antibiotic.

In cases of poor renal protection, for example by insufficient cooling, extended ischaemia causes *acute tubular necrosis*. Depending on the extent of damage, the manifestations range from a mild decrease in glomerular filtration rate and concentrating ability to acute renal failure and anuria. The kidney can recover if the waste products are eliminated during the recovery period either by the contralateral kidney or by haemodialysis. Before expectant treatment is chosen, however, ureteral obstruction and renal artery thrombosis must be ruled out. If sonography reveals a dilated collecting system, the former is the most probable cause, and the level of obstruction must be determined by antegrade or retrograde pyelography. Without evidence of dilatation, a technetium scan with rapid-sequence scintigraphy should be obtained at once to rule out arterial non-perfusion. If no radioisotopes reach the kidney, renal artery occlusion is likely to have occurred and acute renal anteriography is indicated. Although kidneys have been shown to recover up to 24 hours after ischaemic infarction, this diagnostic sequence must be performed without delay. Regional fibrinolysis is too hazardous immediately after open surgery (Karnik et al 1985), so that the only chance of saving the kidney in this situation lies in immediate surgical repair of the arterial lesion.

Prolonged *discharge of urine* from the drain is usually caused by impaired drainage due to a missed calculus, clot, or ureteral obstruction. If urine drains for more than four days, a self-retaining ureteral stent is inserted. Occasionally leakage results from incorrect positioning of the tip of the drain immediately adjacent to incision in the collecting system; careful retraction of the drain by 1–2 cm rapidly dries up the wound. Permanent urinary fistulae are extremely rare and, when present, they are always the result of obstruction below the level of the surgery. Urinary extravasation may cause severe problems if the wound is improperly drained, for example, if the drain is situated outside the perirenal fascia. *Urinoma* formation is usually heralded by fever and flank pain, but may occur inconspicuously. A high degree of suspicion should therefore be directed towards this potential complication and any unexplained fever, flank pain, or delayed healing should be investigated initially by ultrasonography, an antegrade pyelogramme if the nephrostomy is still in place, or excretory urography with delayed films. The situation can usually be corrected by draining the kidney properly with an internal stent or a nephrostomy, and by draining the urinoma percutaneously.

In the pre-ESWL era the most frustrating complication of any stone operation was the calculus left behind. Although the availability of ESWL should still not be an excuse for a less careful attempt at complete stone removal once open surgery is decided upon, retained stones can be treated in this manner highly successfully some days after the operation. Likewise, if a calculus below the level of surgery was overseen and resulted in obstruction and/or extravasation, it can be treated endoscopically, or by ESWL, just like any other ureteral stone in the immediate postoperative period.

SURGICAL ACCESS TO THE URETER

With almost complete elimination of the need for ureterolithotomy, surgical exposure of the ureter only becomes necessary in rare and difficult situations today. It always requires ample exposure, so that most of the minimally muscle splitting incisions used for specific situations 10 years ago, such as the posterior lumbotomy for high ureteral stones, the gridiron incision for mid-ureteral stones and a transvesical or transvaginal approach for intramural stones, have become obsolete.

The entire proximal half of the ureter is best approached by a modified 12th rib supracostal incision, which is carried farther anterior to the tip of the rib.

The distal half of the ureter is best approached by a suprainguinal extra-peritoneal access. Depending on the exposure needed, the skin is incised in an oblique direction along a line from the pubic tubercle upwards to a point about two finger-breadths anterior to the superior iliac crest. The external oblique abdominal muscle and the internal oblique and transverse abdominal muscles are severed in the same direction. After ligating and transecting the epigastric vessels the peritoneal fold is reflected medially to expose the ureter. It can be identified without problems, either where it crosses the common iliac artery, or where it crosses immediately below the umbilical artery. The latter structure is routinely divided and ligated.

Prior to closure of the wound, the ureteral bed is drained with a tube drain of silicone rubber, which has some perforations cut into its draining end. The tip of the drain should not be in direct proximity to a ureterotomy, but in a dependent position 2–3 cm away to reduce the risks of urinary extravasation; it is led out through a separate stab incision. The wound is closed in layers.

URETEROLITHOTOMY

Today, ureteral stones require open surgical intervention only in situations where endoscopic techniques and ESWL fail. In general, these failures are concomitant with a complication of previous therapeutic interventions, in particular endoscopic manipulation. Urinary extravasation, an impacted ureteral basket, ureteral avulsion and an impacted obstructing ureteral stone are the rare, but typical scenarios.

The ureter is approached extraperitoneally, through a wide incision, and snared above and below the stone. The ureteral wall is incised with a scalpel directly onto the stone in a longitudinal direction. As soon as the mucosa is opened, the incision is enlarged with angular scissors, so that the stone can be extracted with nerve hooks. The ureter is then probed in both directions to ascertain complete stone removal and it is irrigated copiously. With the slightest possibility of obstruction, extravasation, or difficult closure, a self-retaining stent is inserted into the ureter, taking care to position the two ends properly within the bladder and renal pelvis. The ureteral wall is then approximated with interrupted sutures of 5-0 chromic catgut, taking care not to cause obstruction. A watertight closure is not needed, but precise drainage of the ureteral bed is essential. Even if closure is not achieved, internal stenting and good drainage are usually sufficient for spontaneous healing of the lesion.

Ureteral avulsion at ureteroscopy almost always occurs just proximal to the ureterovesical junction. In this situation, as well as with any significant damage of the distal third of the ureter, the safest solution is ureteral reimplantation with the psoas hitch technique (Riedmiller et al 1984). More extensive damage requires ureteral substitution (see p. 225).

SURGERY FOR LOWER URINARY TRACT STONES

Stones in the urethra and bladder are, currently, almost exclusively removed by endoscopic techniques. Open surgery is only indicated for the exceptionally large vesical stone or the situation where a large bladder diverticulum, or large benign prostatic hyperplasia, also requires open surgery. The surgical techniques are standardized and need no further comment.

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A guide to treatment selection

M Marberger, J M Fitzpatrick

Introduction

For at least 80% of all stones in the upper urinary tract ESWL 'monotherapy' is the treatment of choice, as it eliminates the problem with a minimum of morbidity and invasiveness. In the remaining 20% the size, number, position and chemical composition of the stone, anatomical characteristics of the urinary tract, or patient specific factors like obesity, orthopaedic deformity, or childhood may render other techniques of stone treatment more advisable, or at least to be combined with ESWL. Several management options have been outlined in the previous chapters, but however clear they may appear, clinical experience with all techniques remains crucial for selecting the optimum approach in difficult and complicated cases. As personal experience and preferences influence the therapeutic decision and various approaches may be equally effective, two of the authors comment on each case.

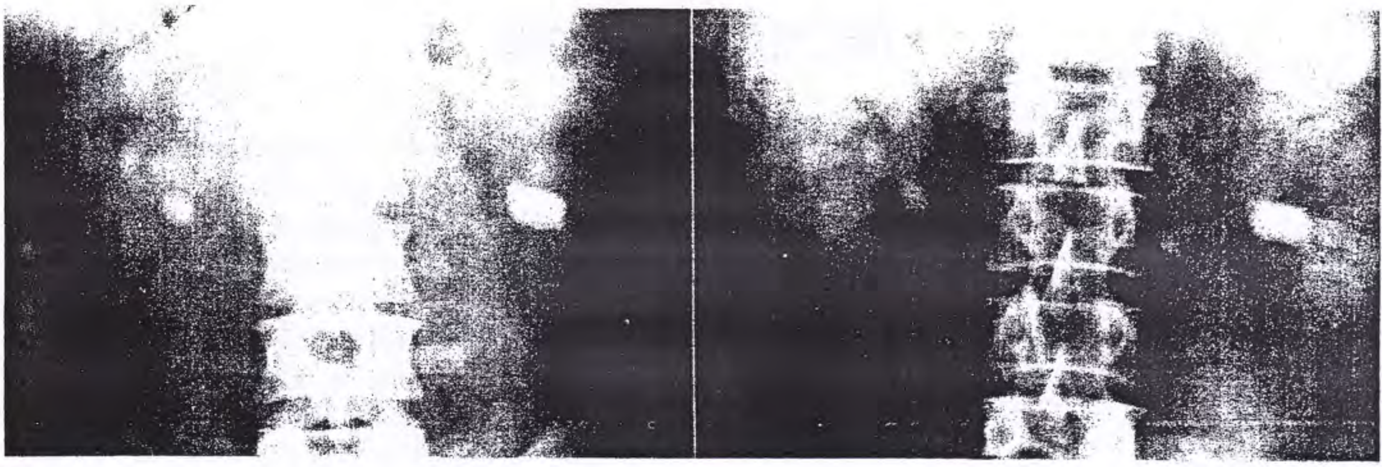


Fig. 9.1

A B

(A, B) Patient 1 (plain film and delayed film of excretory urogram).

PATIENT 1 (Fig. 9.1)

23-year-old male with a history of recurrent flank pain on the right side and no symptoms on the left. Serum creatinine 1.1 mg/100 ml, urine culture sterile, no evidence for metabolic stone disease. Ultrasonography of both kidneys shows a grossly dilated collecting system, but normal thickness of the parenchyma.

M: Both kidneys are severely obstructed by large pelvic stones; the stone on the left measures 3 × 1.8 cm, the stone on the right 2 × 1.6 cm. The radiographic appearance suggests rather soft calcium-oxalate-dihydrate stones, which usually disintegrate readily with ESWL. Provided the ureters are stented, ESWL would probably ultimately be successful. In view of the severe obstruction of both kidneys and the rather large stone mass, which would necessitate long-term follow-up, I would prefer to have one kidney cleared of stone as rapidly as possible. I would opt for percutaneous ultrasonic nephrolithotripsy of the stone on the left, which is ideally positioned for this technique. At the same time I would insert an internal ureteral stent on the right side. The stone on the right could then be treated by ESWL 2–3 days later.

F: I would agree with this approach; because both kidneys are so severely obstructed it is important to relieve the obstruction on both sides. Simply treating the stone on the left side by ESWL would not accomplish this, and so the percutaneous approach is definitely preferable. A double-pigtail stent should be inserted as soon as possible into the right ureter and with ESWL should lead to satisfactory stone destruction.

The stone on the left was completely removed by ultrasonic nephrolithotripsy under general anaesthesia. An internal ureteral stent was placed into the right system at the same time; the stone was disintegrated by electromagnetic ESWL 2 days later, and all stone material was passed within 3 weeks without complications. Stone analysis: calcium-oxalate-dihydrate 87%, calcium-oxalate-monohydrate 13%.

PATIENT 2 (Fig. 9.2)

63-year-old male with a history of recurrent pain in the left upper abdominal quadrant, which was initially investigated by barium enema. When the patient presented with a fever of 24 hours duration, microhaematuria and severe tenderness of the left flank, an excretory urogram was obtained. A urine culture remained sterile, the right upper urinary tract was normal. At the time of admission he had a fever of 38.6°C, but was haemodynamically stable with a normal platelet count.

M: The left collecting system is severely obstructed by a radio-opaque stone about 2 cm in diameter, which is impacted in the ureteropelvic junction. Although the stone also appears to be composed of calcium-oxalate-dihydrate and the voided urine was sterile, the source of fever is most likely the obstructed kidney. The main cause for concern in patients such as these is endotoxic shock, in particular when treated by retrograde manipulation or ESWL without proper drainage of the kidney. I would immediately drain the kidney with a thin nephrostomy tube inserted under local anaesthesia. As soon as urinary infection is appropriately treated and the clinical symptoms of infection have subsided, the stone can be treated by percutaneous nephrolithotripsy or ESWL; as a nephrostomy tube is already in place, it is more convenient to use the former.

F: This patient should be managed initially by the insertion of a percutaneous nephrostomy tube. The patient should be placed on the appropriate antibiotic after sending a sample of the drained urine for culture and sensitivity. Once the infection has subsided, I would recommend that the stone be managed by ESWL, the results in 2 cm renal pelvic stones being excellent. No procedure should be carried out until the patient's temperature has returned to normal for 48 hours; the septicaemia associated with ESWL in an infected kidney, particularly without adequate drainage, can be resistant and prolonged.

The kidney was drained with an 8 F pigtail nephrostomy tube placed through a lower pole calyx as an emergency procedure. *E. coli* was cultured from the urine which was drained from the nephrostomy. The patient became asymptomatic and afebrile within hours. After appropriate antimicrobial treatment for 3 days the stone was removed by percutaneous nephrolithotripsy. Stone analysis: calcium-oxalate-dihydrate.

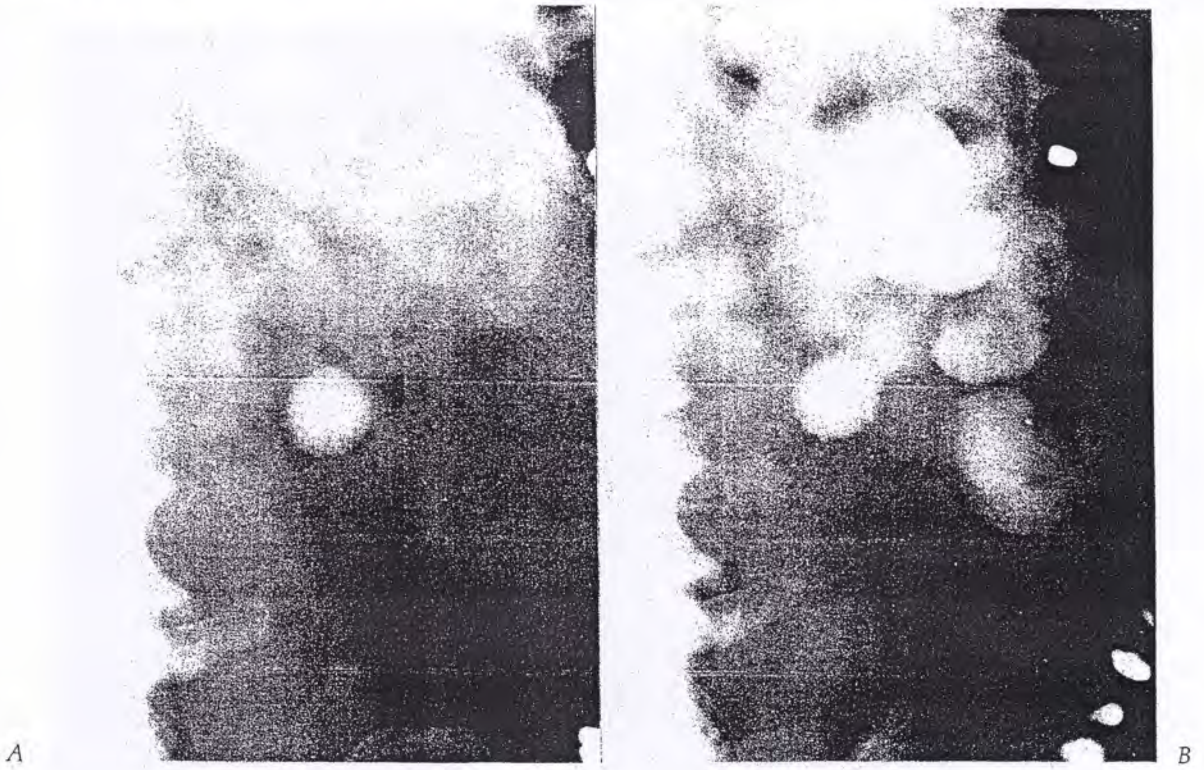


Fig. 9.2
(*A, B*) Patient 2 (plain film and excretory urogram).

IKATAN AHLI UROLOGI INDONESIA
UROLOGI YOGYAKARTA

PATIENT 3 (Fig. 9.3)

42-year-old female with recurrent flank pain and haematuria from the left kidney. Body weight 185 pounds. The only abnormality noted in the urinary tract was the stone-bearing calyceal diverticulum in the upper pole of the left kidney; the urine was sterile.

M: Stone debris clears poorly from calyceal diverticula after ESWL, but in 34% of 32 cases we treated in this manner the kidneys ultimately became stone free. Percutaneous nephrolithotripsy proved successful in 83% of 17 patients, but complications, mainly moderate haemorrhage, occurred in 18%. This kidney is particularly high and the patient's obesity renders percutaneous puncture of the diverticulum rather difficult. As second generation lithotriptors do not need anaesthesia, I would first try ESWL; only if no fragments are passed at all would I resort to percutaneous nephrolithotripsy via a supracostal approach directly onto the stone. Of course, it is essential that careful patient evaluation really confirms the diverticulum to be the cause of the symptoms.

F: It is possible to debate the question as to whether stones in calyceal diverticula actually cause symptoms in patients with flank pain and this finding on X-ray. In this patient, it is virtually certain that the symptoms are due to the large collection of calculi in this calyceal diverticula. In the past, the open surgical approach to treat this case would be simple for the urologist: an incision based on the 11th rib, mobilization of the kidney, clearance of the stone and then obliteration of the diverticulum itself. With the advent of less invasive approaches, it has become easier for the patient than previously.

I would also recommend an initial attempt with ESWL on this stone. The percutaneous route of access to the stone would necessitate a very high puncture with the risk that this might be transpleural. Although this complication could be managed with relative ease, it would make the procedure considerably more complicated, requiring insertion of a chest tube and reinsertion of a track subpleurally.

The patient was treated by piezoelectric shock wave lithotripsy and by 2 weeks had spontaneously passed about one-third of the stone material. Although two more treatments were required on an outpatient basis, the kidney was stone free and the patient asymptomatic 2 months after the treatment was started.

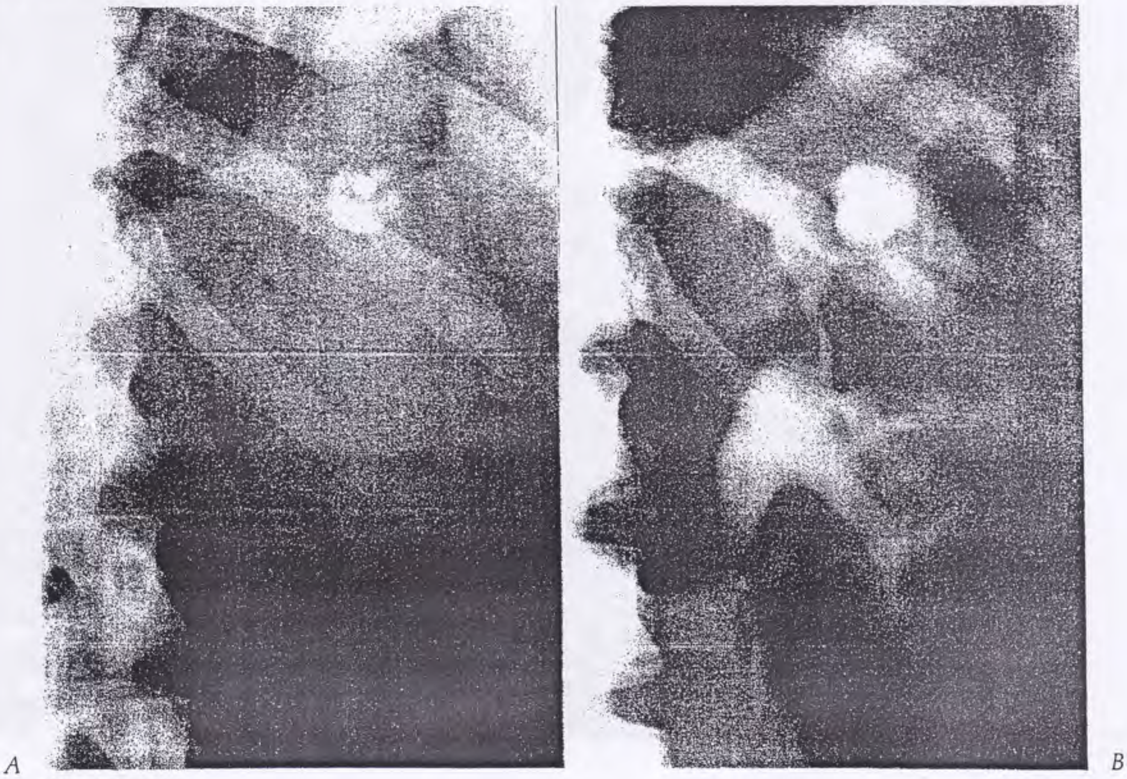


Fig. 9.3
(*A, B*) Patient 3 (plain film and excretory urogram).

PATIENT 4 (Fig. 9.4)

46-year-old male with occasional, slight flank pain on the left. At ultrasonography of the abdomen during a medical check-up, renal stones and hydronephrosis of the left kidney were detected. The patient had never passed a stone, the urine was sterile and the right upper urinary tract normal. Diuresis renography was typical for severe obstruction, but demonstrated good overall function of the kidney; retrograde uretero-pyelography showed obstruction at the ureteropelvic junction suggestive of an aberrant vessel crossing at this level.

M: The stones could probably be removed percutaneously and obstruction could probably be corrected by pyelolysis, but with a redundant collecting system and a kidney which has not previously been operated upon, our results are better with open surgical pyeloplasty, which also simplifies stone removal.

F: A case could be made for the percutaneous approach. The stones would be easy to remove in this manner, with an initial tract into the lower pole calyx. In experienced hands the results of percutaneous division of the pelviureteric junction are good, and a secondary puncture could be made into one of the middle calyces, thus making it easier to visualize and incise the required area. If this were unsuccessful, open surgery could then be undertaken.

An Anderson–Hynes pyeloplasty was performed and all stones were removed at the same time; the stones in the middle anterior calyx were difficult to localize and could only be removed after an intraoperative roentgenogram and with the help of the pyeloscope.

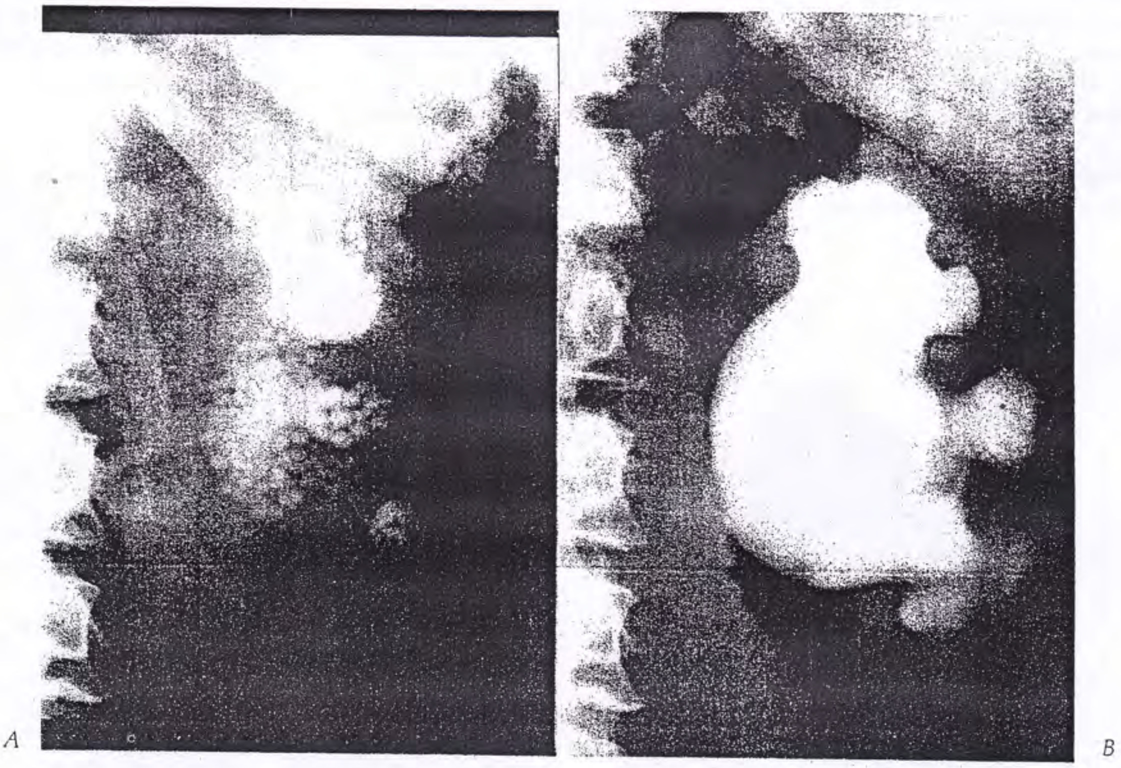


Fig. 9.4
(A, B) Patient 4 (plain film and excretory urogram).

PATIENT 5 (Fig. 9.5)

29-year-old male with a malrotated right kidney, from which a large struvite stone had been removed by pyelotomy 2 years previously; the left kidney was congenitally absent. The patient had recurrent urinary tract infection, but was otherwise asymptomatic and had normal renal function.

M: The patient has recurrent stones in the renal pelvis and a dependent lower pole calyx. The collecting system appears to be non-obstructive and the stones, presumably, are of infectious origin and therefore soft. I would recommend aggressive antimicrobial therapy, insertion of an indwelling ureteral stent and ESWL, even though fragments tend to clear poorly from lower pole calyx with a narrow infundibulum, as in this patient.

F: I would agree with this method of managing the patient described above. Problems may arise because of the anterior position of this calyx in the malrotated kidney, which might make the focusing of the stone somewhat difficult. In anatomically normal kidneys, stones in inferior calyces respond less well to ESWL than stones elsewhere in the kidney; it has been noticed frequently that, although the stones are adequately fragmented, they drain very slowly indeed; 44.3% of patients with inferior calyceal stones treated by ESWL had residual fragments at the time of discharge from hospital and at 3 months only 71.1% were free of stones at follow-up.

In this patient with a complicated drainage system, the result may be even less satisfactory, but I still feel that the best balance between success and non-invasive management for this patient lies in ESWL. This stone should be managed by ESWL.

An indwelling stent was inserted and the stones were fragmented by piezo-ESWL. The renal pelvis cleared of stone material within 3 weeks, but debris remained in the lower pole calyx for 3 months, in spite of complete disintegration and retreatment 1 month after the first session; as the patient had chronic bacteriuria and was experiencing increasing symptoms from the stent, the residual fragments were then removed by percutaneous nephrolithotripsy. In retrospect, primary percutaneous stone removal would have been the better choice, in particular as it proved very simple to enter the collecting system through the posterior middle calyx. Stone analysis: struvite 70%, calcium-oxalate-dihydrate 30%. After complete stone removal urinary infection was cleared.

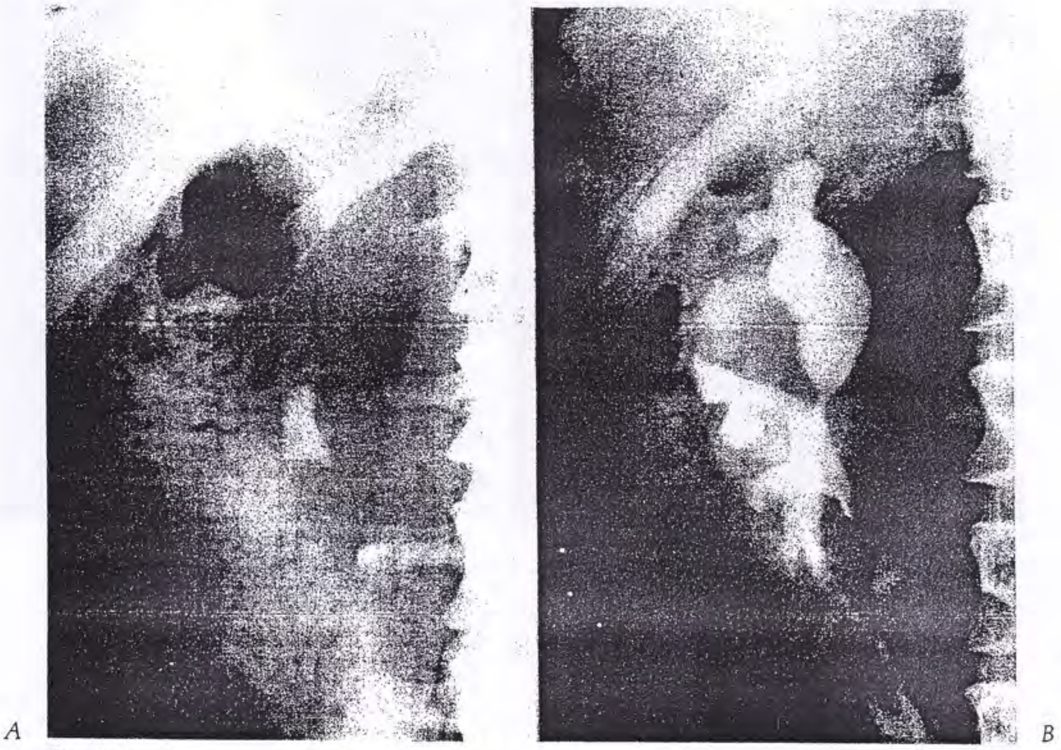


Fig. 9.5
(*A, B*) Patient 5 (plain film and excretory urogram).

PATIENT 6 (Fig. 9.6)

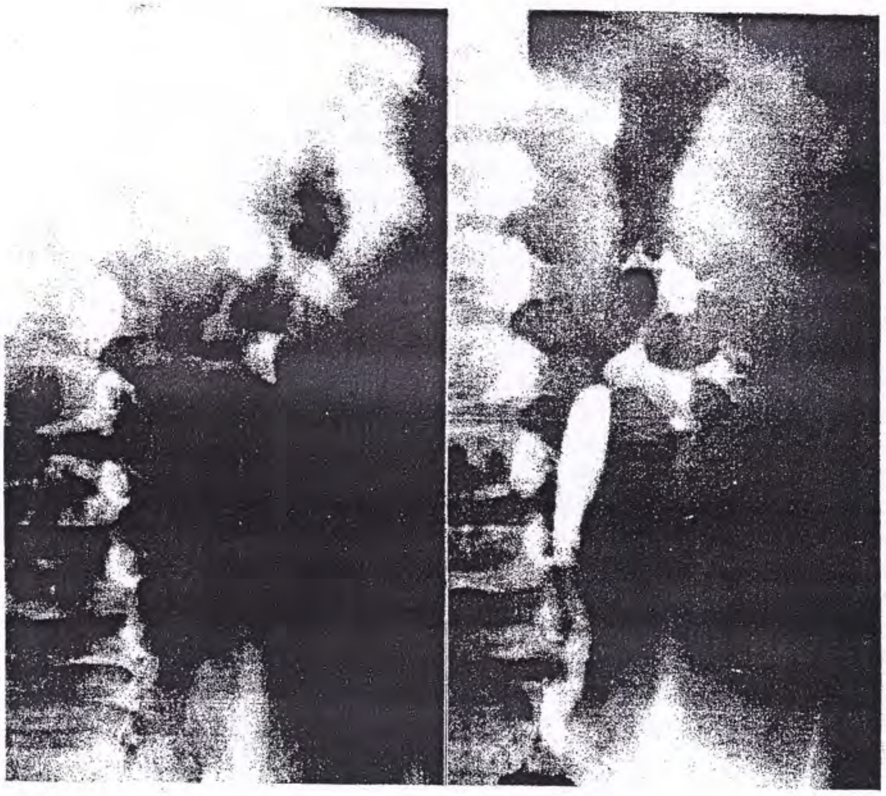
7-year-old girl with urinary tract infection with B. proteus mirabilis *and left flank pain; normal right upper tract, no vesicoureteral reflux, normal lower urinary tract.*

M: Children pass stone fragments more readily and with less problems than adults. Provided an advanced lithotriptor with a small high-pressure focal area and continuous ultrasonic stone localization is available, ESWL is our treatment of choice in children. Based on experience with piezo-ESWL in 57 children, I would treat this child with a staged approach in two to three sessions, so that the stone debris produced per treatment is not too large and a stent is not necessary. The apparently narrow ureteral segment below the stone is only a functional reaction to the stone and not a stricture. If this technique is not available, I would recommend percutaneous nephrolithotripsy using an 18 F nephroscope. Precise antimicrobial therapy is essential.

F: The first point to make about this case is that the apparently narrow area below the pelviureteric junction is almost certainly not strictured; it is caused by spasm, related to the chronic infection associated with the stone. In addition, the calyces look cupped and there is an absence of clubbing. A DTPA or MAG-3 scan with frusemide will confirm this.

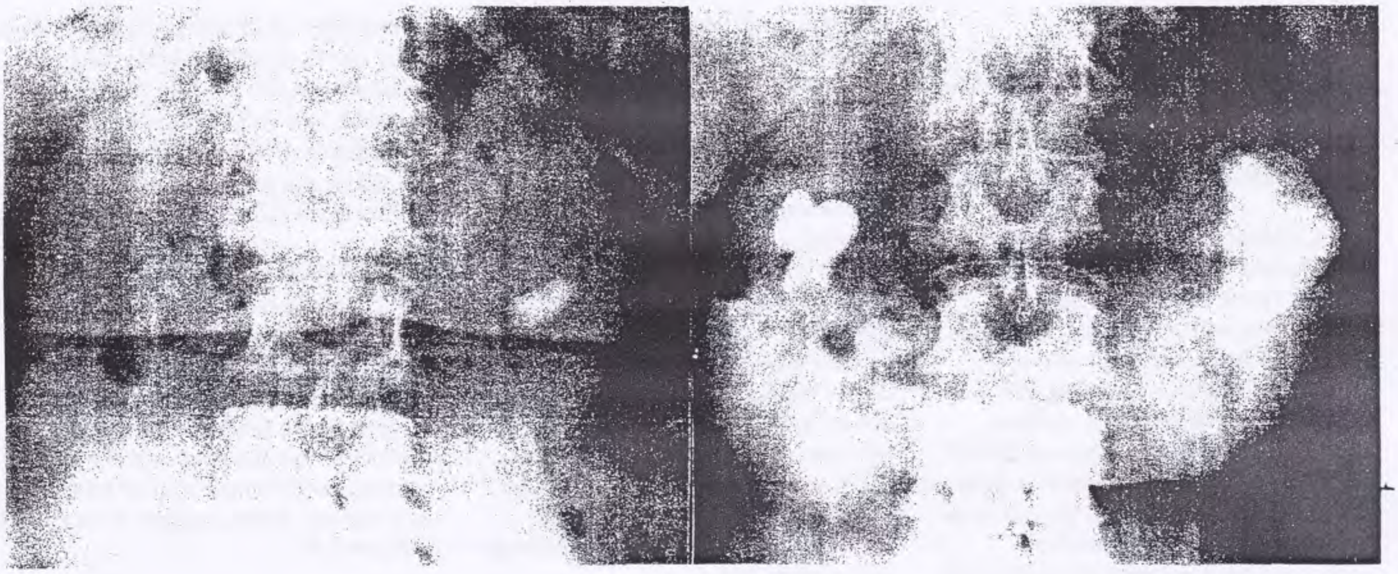
The method of choice to treat this stone is by ESWL. It will probably take two sessions and it is unlikely that an internal stent will be required, as it has been shown that stones in children fragment and pass more easily than in the adult (see Ch. 7).

The child was treated by staged piezo-ESWL in two sessions at an interval of 2 weeks; no anaesthesia or analgesia was used and the second treatment session was performed on an outpatient basis. In spite of the absence of a stent, no complications occurred and the child was stone-free 6 weeks after treatment was started. Stone analysis: 54% apatite, 46% struvite.



A *B*

Fig. 9.6
(*A, B*) Patient 6 (plain film and excretory urogram).



A *B*

Fig. 9.7
(*A, B*) Patient 7 (plain film and excretory urogram).

PATIENT 7 (Fig. 9.7) ✓

61-year-old female with severe recurrent left flank pain and haematuria. No urinary infection, normal lower urinary tract.

M: Stone debris passes poorly from horseshoe kidneys after ESWL, obviously because of relative obstruction at the ureteropelvic junction. On the other hand, these kidneys are particularly low in the abdomen and therefore very well accessible for percutaneous nephrolithotripsy. I would select an approach through a posterior upper pole calyx. In 24 stone-bearing horseshoe kidneys we treated in the last 6 years, complete stone removal was achieved in 13 out of 18 kidneys treated percutaneously, compared to only 1 out of 5 treated by ESWL monotherapy.

F: The drawbacks associated with treating stones in horseshoe kidneys with ESWL are alluded to in Chapter 7. Further problems would be associated with this stone, which is in the lower part of the left hand moiety, probably extending slightly into the isthmus. For this reason it would be lying quite far anteriorly, and if there were a high insertion of the ureter into the renal pelvis, the fragments would have to drain uphill before passing into the ureter. Because of the low lying position of the kidney, percutaneous access would be simplified and the stone could be broken up by ultrasound or electrohydraulic lithotripsy. This would therefore be the preferable way for removing this stone.

The stone was completely removed by percutaneous ultrasonic nephrolithotripsy without any complications. Stone analysis: calcium-oxalate-dihydrate 88%, calcium-oxalate-monohydrate 22%.

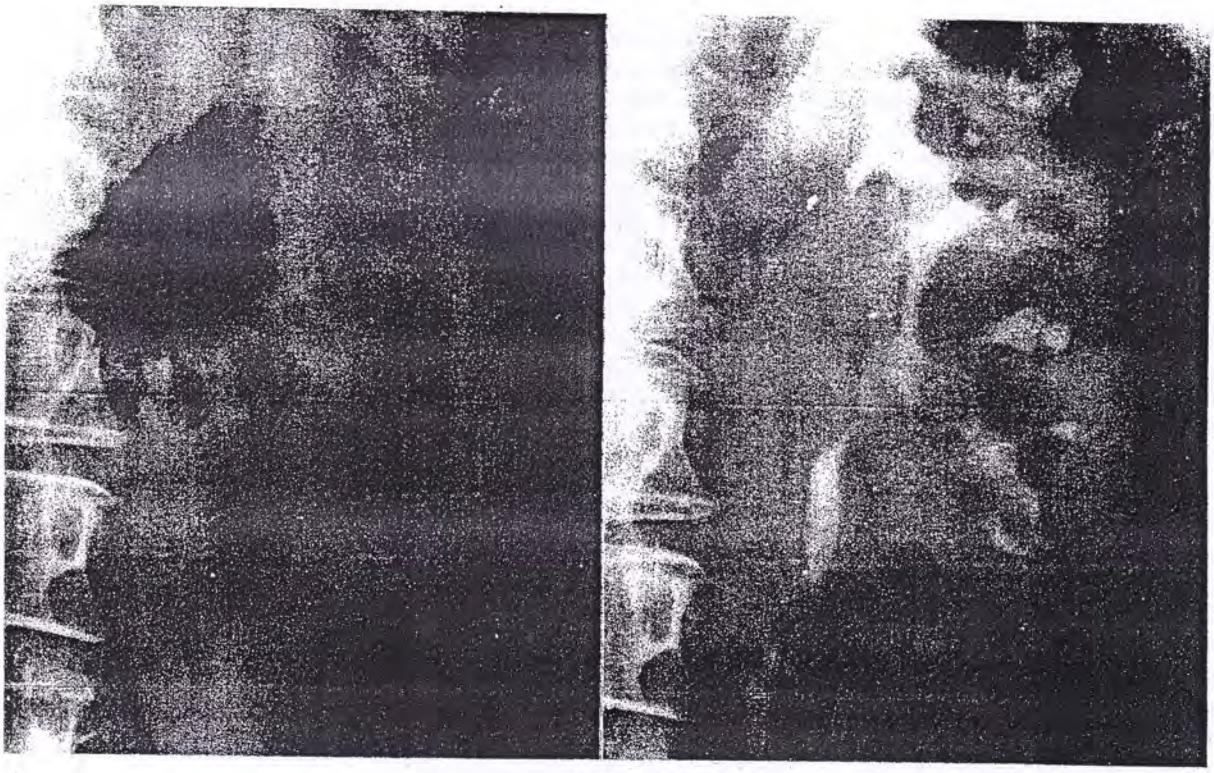
PATIENT 8 (Fig. 9.8)

62-year-old female with history of renal pain and spontaneous passage of stones some years previously. Recurrent haematuria and slight flank pain on the left, no history of gout. The urine was sterile and had a constant pH < 5.5. Ultrasonography confirmed the radiolucent partial staghorn stone in the left kidney. The right upper tract was normal.

M: At least 90% of all radiolucent stones are composed of uric acid and can be treated successfully by oral dissolution. This is significantly accelerated by adjunctive ESWL, as the surface increases multifold with fragmentation. With the availability of painless ESWL, and ultrasonic stone localization, we routinely combine dissolution therapy with ESWL. As it is difficult to detect the fragments and to follow their passage down the ureter, we routinely insert an indwelling stent until the patient is stone free. Of course, adjunctive oral alkalinization of the urine, allopurinol and the reduction of dietary purine intake remains essential.

F: These X-rays depict a rather large radiolucent calculus in the left kidney, composed of uric acid. It is perfectly acceptable to manage this by insertion of a double-pigtail stent and administration of oral sodium bicarbonate. This will result in dissolution of the stone, and the stent will prevent any possibility of ureteric obstruction. The entire treatment will be required for about 6 weeks and a follow up ultrasound should be performed at this time. ESWL is a useful adjunct in this case. The patient will be rendered stone free much quicker if, after the insertion of the double-J stent, a course of ESWL is given. This will mean that the length of time the patient will need to take the bicarbonate will probably be halved. The stone will be visualized easily on the ultrasound based machines; those requiring X-ray localization will need the administration of intravenous dye.

The patient was started on allopurinol, oral alkalinization therapy and subjected to a total of three piezo-ESWL treatments. Within 7 weeks the kidney was stone free, although the stent had to be changed once because it became clogged and the patient experienced pain. Urinalysis: 100% uric acid.



A *B*

Fig. 9.8

(*A, B*) Patient 8 (plain film and excretory urogram).

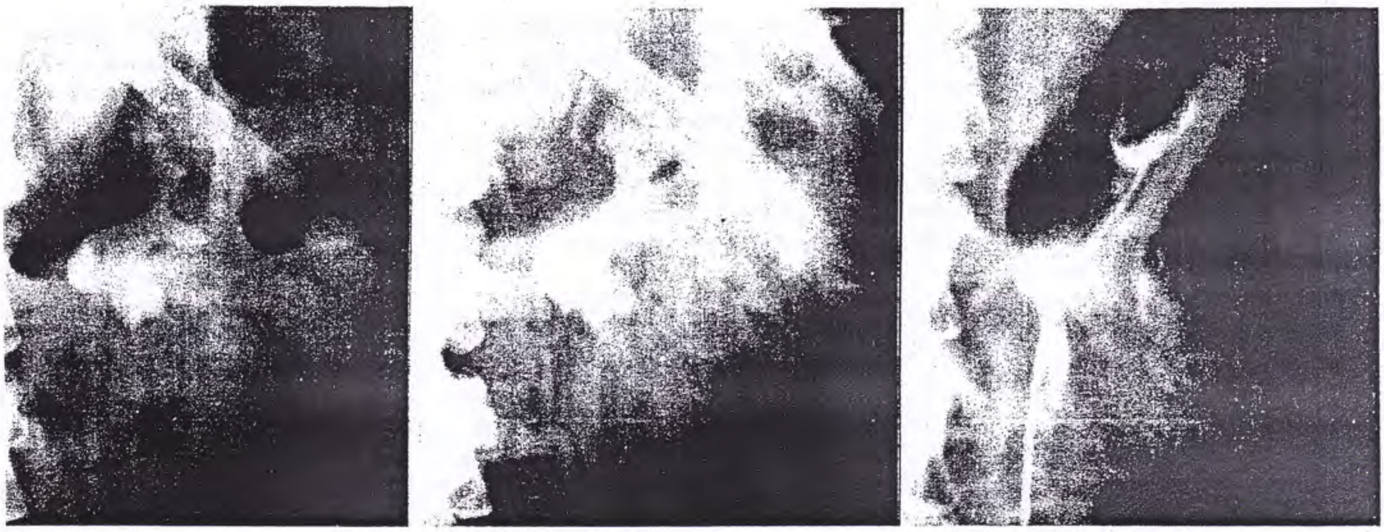


Fig. 9.9
(*A–C*) Patient 9 (plain film, delayed film of excretory urogram, retrograde pyelogram).

PATIENT 9 (Fig. 9.9)

32-year-old female, recurrent urinary tract infection for years, recurrent flank pain and fever up to 39°C for 14 days. Ultrasonography showed a calculus in the left kidney, which seemed to fill out the entire, severely dilatated collecting system of the significantly enlarged organ. In contrast, the radio-opaque stone visible on the KUB (Fig. 9.9A) appeared to be considerably smaller. The kidney showed no dye excretion at excretory urography (Fig. 9.9B) and at retrograde pyelography the collecting system appeared to be completely moulded with soft masses around the central stone. The right kidney and renal function were normal; the urine was infected with E. coli.

M: This matrix stone formed around a core of a more calcified stone. Because of their rubber-like consistency, matrix stones cannot be disintegrated by ESWL, but can easily be extracted percutaneously. As the radio-opaque segment is also accessible to a percutaneous approach, percutaneous nephrolithotripsy is the treatment of choice.

F: It can be quite frustrating to treat this type of stone by ESWL and, after several courses of treatment, to see no satisfactory result. Matrix stones are soft and surrounded by rubbery material which cannot be seen on straight abdominal X-ray. It is completely resistant to ESWL. It is also certain that, if this stone were treated by ESWL and some degree of fragmentation obtained, early recurrence would be very likely. The best approach to this stone is by percutaneous nephrolithotomy. The matrix can be removed with a grasping forceps and the stone itself broken up by ultrasound. Complete clearance can be achieved in this way.

The stone was removed percutaneously immediately after it was demonstrated by retrograde pyelography; the matrix part of the stone was plucked from the collecting system with forceps and the soft radio-opaque core of the stone was removed with ultrasonic lithotripsy; it consisted of 90% calcium-magnesium-ammonium-phosphate.

PATIENT 10 (Fig. 9.10)

79-year-old male with severe symptoms of lower tract urinary obstruction and recurrent haematuria, obviously caused by benign prostatic hyperplasia and a radio-opaque bladder stone 3 cm in diameter. Excretory urography also showed discrete calcification in the areas of the calyces of the left kidney, but the kidney appeared non-obstructed. Axial computerized tomography showed the stones to be within the collecting system and to form a calcified shell of the collecting system. The urine was sterile and the right upper tract normal; no metabolic disorder explaining the calcification was detected.

M: This is not nephrocalcinosis, but rather lining of major segments of the renal collecting system with stone material. Perhaps this represents the beginning of a staghorn stone formation. If this condition is to be treated at all, I would recommend ESWL, preferably with a painless lithotriptor of low morbidity and invasiveness.

F: I think that, in this case, I would simply observe the patient rather than treat the stone. If the patient insisted on treatment, I would suggest ESWL.

The patient was subjected to transurethral resection of the prostate and electrohydraulic lithotripsy of the bladder stone. Subsequently, the calcifications in the left kidney were treated by piezo-ESWL on an outpatient basis in two sessions. The patient became asymptomatic after lower tract outflow obstruction was removed, but no stone material was passed from the left kidney and the radiographic appearance of the left kidney did not change. Following this, treatment was stopped and the situation remained unchanged during a further 2 years of follow up.

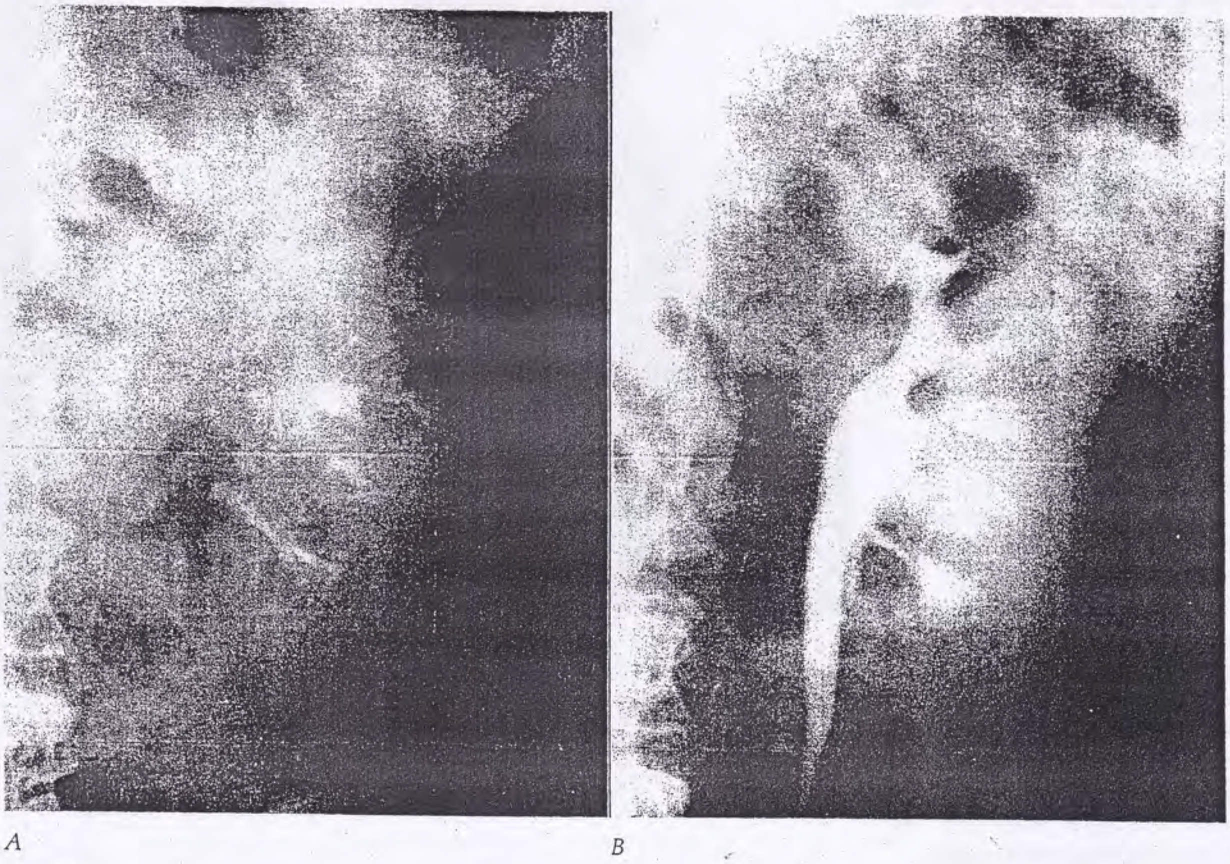


Fig. 9.10
(*A, B*) Patient 10 (plain film and excretory urogram).

ATIENT 11 (Fig. 9.11)

1-year-old female with recurrent urinary ract infection over years. Normal right idney and lower urinary tract, urinary nfection with E. coli, *normal function of he left kidney in spite of almost complete taghorn stone; note severe calcification in he aortic wall.*

M: In spite of the extensive stone and he rather poor condition of the patient, he stone must be removed to control rinary infection; a nephrectomy is ruled ut by the good function of the organ. I vould choose a combined approach: irst I would debulk the stone with ultrasonic nephrolithotripsy through an ipper or lower pole calyx, which should ermit removal of the mass of the stone n the pelvis and lower and upper pole; he remaining calyceal extensions could e treated by staged piezo-ESWL on an utpatient basis under the protection of n indwelling urethral stent. If the ragments are not passed completely, nother percutaneous session may ecome necessary, resulting in a sandwich-type treatment'. The timing f the various treatment stages mainly epends on logistic limitations and hould be decided individually. There is o evidence available that ESWL onstitutes a danger in patients with ascular calcifications, even if they are within the high-pressure zone.

F: This is a large staghorn calculus with multiple individual calyceal fragments. Treating this uniquely with ESWL would result in multiple treatment sessions with variable clearance rates. Initial percutaneous debulking of the large central fragment is essential. This in itself would be quite a long procedure, but should result in the clearance of the fragment in the pelvis, lower pole infundibulum, upper pole infundibulum and upper pole calyx. The peripheral calyceal fragments would then be treated subsequently by ESWL. One of the complications associated with percutaneous nephrolithotripsy or ESWL of infected stones is a severe and resistant septicaemia. I have noted that, in spite of adequate prophylaxis, the patient may develop a pyrexia resistant to even the appropriate antibiotics and which takes some days to disappear.

Before embarking on the management of such a case, it would be essential to assess completely the patient's renal function. Not only could a glomerular filtration rate as measured by creatinine clearance be required, but also divided renal function by MAG-3 renal scan.

The patient had a percutaneous debulking procedure under general anaesthesia, which succeeded in clearing the renal pelvis, upper pole and part of the lower pole. A stent was then inserted and the remaining stone material was treated by piezo-ESWL in three sessions over a period of 3 months. The stent had to be changed once after an attack of fever, but otherwise no complications occurred. As an anterior middle calyx still contained debris after 5 months, it was cleared by percutaneous nephrolithotripsy. Urinary infection cleared permanently after the kidney became stone free.

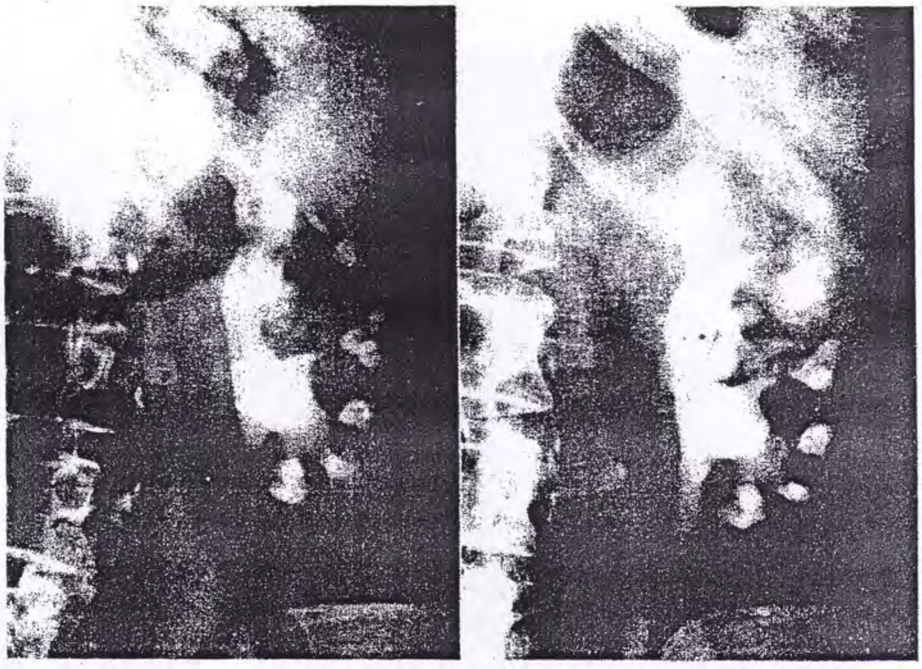


Fig. 9.11
(*A, B*) Patient 11 (plain film and excretory urogram).

PATIENT 12 (Fig. 9.12)

52-year-old male with mild gastrointestinal symptoms of uncertain origin for years, otherwise asymptomatic. The complete staghorn stone in the horseshoe kidney was discovered incidentally. The patient had no hypertension and no evidence of a significant metabolic disorder; a urine culture remained sterile, serum creatinine 1.1 mg/100 ml.

M: In horseshoe kidneys with a very large stone mass, stone removal should be combined with correction of relative outflow obstruction at the ureteropelvic junction as the most likely cause of stone formation. This is achieved by resecting the isthmus of parenchyma between the renal units, bilateral pyeloplasty and bilateral nephropexy. The entire procedure can be performed in one session through a midline approach.

F: The problems associated with the management of stones in horseshoe kidneys have been alluded to in Chapter 7. ESWL or percutaneous nephrolithotomy should only be considered if the stone burden is small, with the former method being less likely to succeed than the latter.

In this case there is a relatively huge stone burden and it is unlikely that the less invasive methods of treatment would be entirely successful. In addition, it is very difficult to gain information from the intravenous urogram as to whether there is a concomitant pelviureteric junction obstruction on both sides. Dye can be seen in the ureter on the left side, but not on the right side. It is essential that a MAG-3 scan with frusemide be carried out in this patient to decide whether either side is obstructed.

I would approach each side separately. Complete clearance of stone from each moiety is essential and the best incision to gain access would be a 'hemichevron'. In addition to a nephrolithotomy, I would perform a pyeloplasty if a pelviureteric junction obstruction were present.

The patient was subjected to open pyelolithotomy on both sides, with resection of the isthmus and bilateral pyeloplasty; most peripheral stones could also be removed by flushing or nephroscopy, but multiple residual stones remained in various calyces after this procedure. They were extracted by bilateral percutaneous nephrolithotripsy through nephrostomies placed in an upper pole calyx on each side, again in one session, rendering the patient stone free. Stone analysis: calcium-apatite 91%, uric acid 9%.

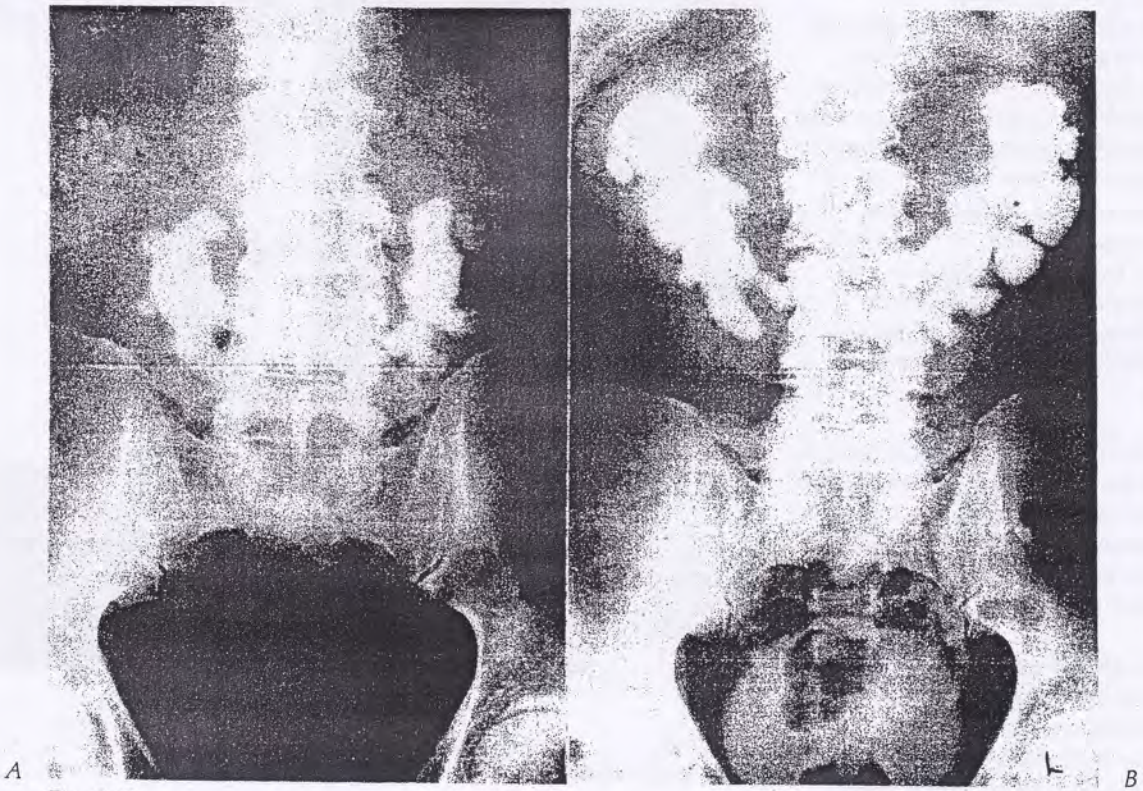


Fig. 9.12
(*A*, *B*) Patient 12 (plain film and excretory urogram).

PATIENT 13 (Fig. 9.13)

36-year-old male with a long history of recurrent urinary tract infection, fever, bilateral flank pain and dysuria. The right kidney was atrophic and contracted from an obstructing pelvic calculus and showed no residual function on the renogram. A pyelolithotomy had been performed on the left 10 years previously. The lower urinary tract was normal. Urine was infected with Pseudomonas aeruginosa *and the blood pressure was normal; serum creatinine 1.3 mg/100 ml. At previous urological consultations elsewhere, removal of the stone had been considered too risky, but the patient now experienced recurrent symptoms of acute pyelonephritis.*

M: Any stone filling a major part of the collecting system of the kidney will damage and ultimately destroy the organ, especially if it is infected. Even if it is initially 'asymptomatic', it must be removed, provided overall renal function justifies the effort; the fact that it occurs in a solitary kidney does not alter this principle. The major problem here is that there is a large stone mass in an intrarenal collecting system. With open surgery a major nephrotomy cannot be avoided, as the perihilar region appears scarred. As the bulk of the stone lies in the renal pelvis and easy-to-reach calyces, it should be accessible to percutaneous nephrolithotripsy, if necessary in several sessions.

F: This stone must be treated in order to prevent the patient's symptoms of acute pyelonephritis and because to leave the stone in place would be to condemn the patient to gradual chronic renal failure, associated with chronic ill health.

This is a difficult case to treat, because of the previous surgery and the fact that the collecting system is entirely intrarenal. I do not believe that treatment of this patient with ESWL would effect complete stone clearance. The choice therefore lies between percutaneous nephrolithotripsy or open stone removal.

Neither would be easy, but the percutaneous approach would be preferable. It is unlikely that this could be achieved in a single session, but it would appear that satisfactory access to the entire stone could be achieved by a puncture in the lower pole.

If it were felt that open surgical removal were to be offered to the patient, the choice would be between multiple radial nephrotomies and the anatrophic nephrolithotomy. These techniques are described elsewhere (Ch. 8). It is likely that this would be a case for the anatrophic nephrolithotomy, as access to the renal pelvis for a combined extended sinus and radial nephrotomy would be extremely difficult.

After aggressive antimicrobial treatment, stone removal was started with ultrasonic nephrolithotripsy through a tract in the posterior lower pole calyx. The procedure had to be stopped after about one-third of the kidney was cleared because haemorrhage obscured vision; it was completed in two more sessions over a 14-day period, which also involved extensive flexible nephroscopy. Serum creatinine rose intermittently to 2.2 mg/100 ml, but had normalized when the patient was discharged on the 16th operative day. A small residual stone remained in an interior middle calyx, which did not increase in size in the following 10 months, but the urine could not be sterilized permanently in spite of appropriate antibiotic treatment.

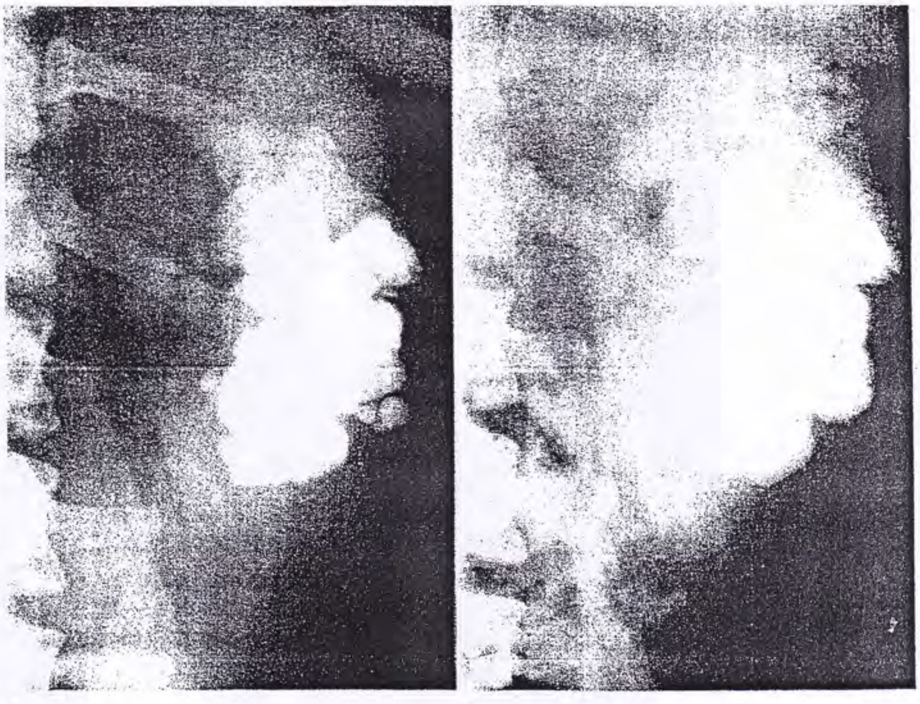


Fig. 9.13
(*A, B*) Patient 13 (plain film and excretory urogram).

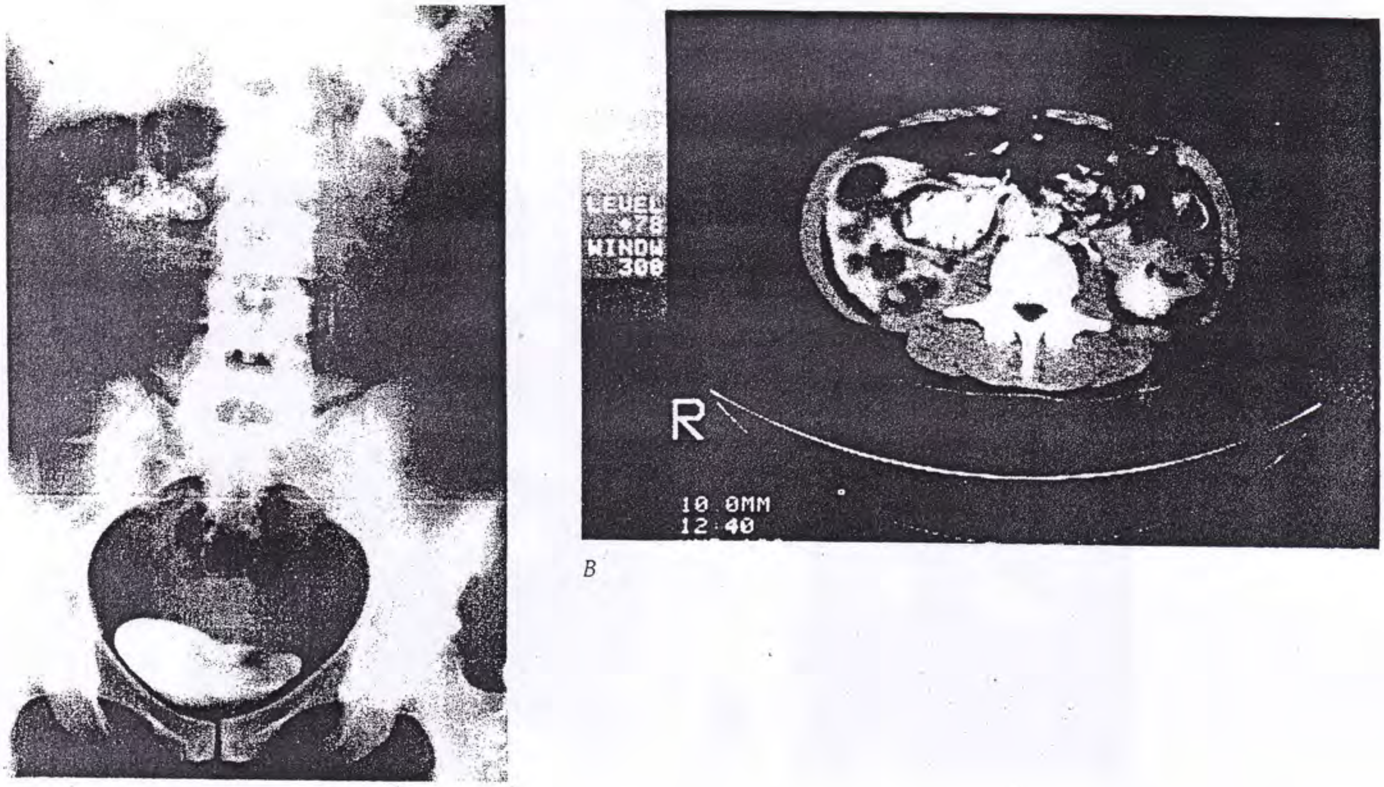
PATIENT 14 (Fig. 9.14)

27-year-old female with recurrent attacks of flank pain and fever over a 3-year period. The symptoms deteriorated in the last 2 months with a rapid loss of weight and increasing fatigue. Serum haemoglobin 7.9 mg/100 ml, serum creatinine 0.9 mg/100 ml, urinary infection with E. coli, *no hypertension. The right kidney showed no excretion of dye (Fig. 9.14A). A perirenal abscess was ruled out by computerized tomography (Fig. 9.14B). The left kidney was normal.*

M: This is an end-stage pyonephrosis and the kidney has to be removed as rapidly as possible.

F: The left kidney is hypertrophied and the right kidney is non-functioning. The CT scan shows a large right kidney and it is almost certain that this is a case of xanthogranulomatous pyelonephritis. A nephrectomy is required with wide exposure from the incision, as it is likely that the kidney will be adherent to the surrounding structures.

An F8 percutaneous nephrostomy was inserted on an emergency basis upon admittance, which subsequently only drained pus. Culture identification and sensitivity testing from the nephrostomy also identified *E. coli*. After short-term antimicrobial therapy and administration of 3 units of blood, a perifascial nephrectomy was performed. The kidney was found to be completely destroyed by pyonephrosis secondary to an obstructing pelvic stone. Further recovery was uneventful and the patient was discharged with sterile urine.



A

B

Fig. 9.14
(*A, B*) Patient 14 (excretory urogram and axial computerized tomography).

PATIENT 15 (Fig. 9.15)

72-year-old male with chronic urinary tract infection over 20 years. Complete bilateral staghorn stones were known to be present for 3 years, but removal was not attempted because of borderline renal function. Serum creatinine was stable around 6.0 mg/100 ml for over a year until, after an attack of right flank pain and fever, the patient suddenly went into end-stage renal failure and required haemodialysis.

M: These kidneys cannot be cleared of stones and, even if this were possible without losing the last bit of parenchyma, infection could probably never be eradicated from the deformed collecting system. Acute renal failure obviously occurred because a calyceal extension dropped into the right ureter and caused acute obstruction. If any procedure is indicated at all, it should be limited to removing this urethral stone in an attempt to get the patient off haemodialysis again by eliminating obstruction. ~~Kidneys with poor function do not eliminate stone debris after ESWL satisfactorily~~, so that I would remove this ureteral stone by percutaneous nephrolithotripsy, even though the percutaneous puncture may also result in some loss of nephrons.

F: A case can be made for bilateral open nephrolithotomy, commencing urgently with the right side. The renal parenchyma would be thin, so renal artery occlusion would probably not be required when performing nephrotomies; these could be carried out with the help of the Doppler ultrasound probe. Clearly, also the stone in the right ureter would have to be removed. I have carried out 41 such cases in patients with a GFR of less than 20 ml/min with 1 perioperative mortality. Dialysis in the postoperative period was required in 1 patient. All were saved from long-term dialysis. Operating on these cases generally results in an improvement in their general health, even if the glomerular filtration rate was 20 ml/min, or less.

The obstructing stone in the right ureter was removed by percutaneous nephrolithotripsy without complications. The patient did come off dialysis and become asymptomatic, but chronic haemodialysis had to be initiated again 2 months later because of progressive renal failure.

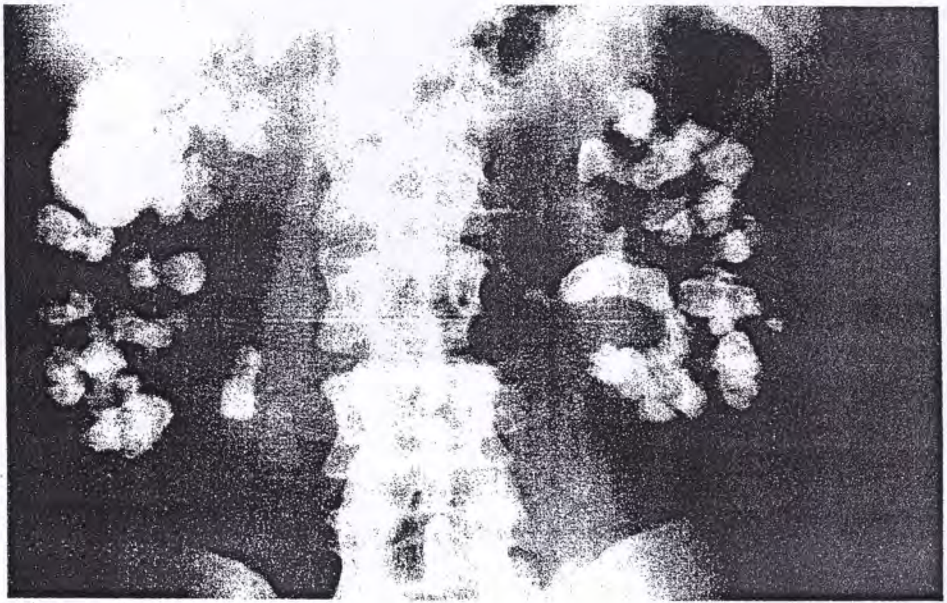


Fig. 9.15
Patient 15 (plain film).

PATIENT 16 (Fig. 9.16)

32-year-old male, who had passed stones after episodes of renal colic several times previously. He was now admitted because of severe recurrent attacks of left flank pain and vomiting. He was afebrile, had sterile urine and a normal left upper urinary tract.

M: As the severely obstructed left kidney does not appear to be infected, immediate relief of obstruction is not necessary. I would therefore opt for ESWL in situ of the ureteral stones. In our experience, stones of this type and position can be localized both by fluoroscopy and ultrasonography. A success rate of > 80% is achieved with this primary choice of treatment. If an advanced lithotriptor is used, no anaesthesia or even aggressive intravenous sedation/analgesia is needed. The invasiveness of ESWL in situ is considerably lower than that of retrograde ureteral manipulation to push the stone back into the kidney and disintegrate it there. With severely obstructed tracts, like in this patient, we failed to flush the stone back into the kidney in 36%. Even if the stone is successfully mobilized, the overall results are only marginally better in spite of the added trauma of ureteral manipulation. ESWL in situ has a higher retreatment rate, but as anaesthesia is not required this is mainly a logistic problem. The peripheral calyceal stones could be treated later.

F: Stones this close to the vertebral column can be very difficult to position with the Siemens Lithostar. When the shockhead is elevated, it pushes the rigid vertebral column and the relatively rigid erector spinae muscle away from it. The patient is placed in a position convex to the shockhead and strapped to the table. Any calculus can be positioned in the focus, although this does not include stones lying over the bony pelvis.

The stone was disintegrated by ESWL in situ with electromagnetic lithotripsy, using 3000 impulses at 19 kV. About two-thirds of the stone mass, which mainly formed the proximal segment of the stone, was subsequently dispersed throughout the dilated collecting system, but larger fragments still remained in place and caused obstruction. The patient was treated again 4 days later with 3000 impulses at 19 kV. He started passing fragments 24 hours later and, after two episodes of renal colic, the ureter was stone free 1 week later. The calyceal stones were disintegrated by piezo-ESWL on an outpatient basis at routine 1-month follow-up examination. At the 3 months follow-up examination the patient was asymptomatic, stone free and unobstructed. Stone analysis: 92% calcium oxalate-monohydrate, 8% calcium-oxalate-dihydrate.

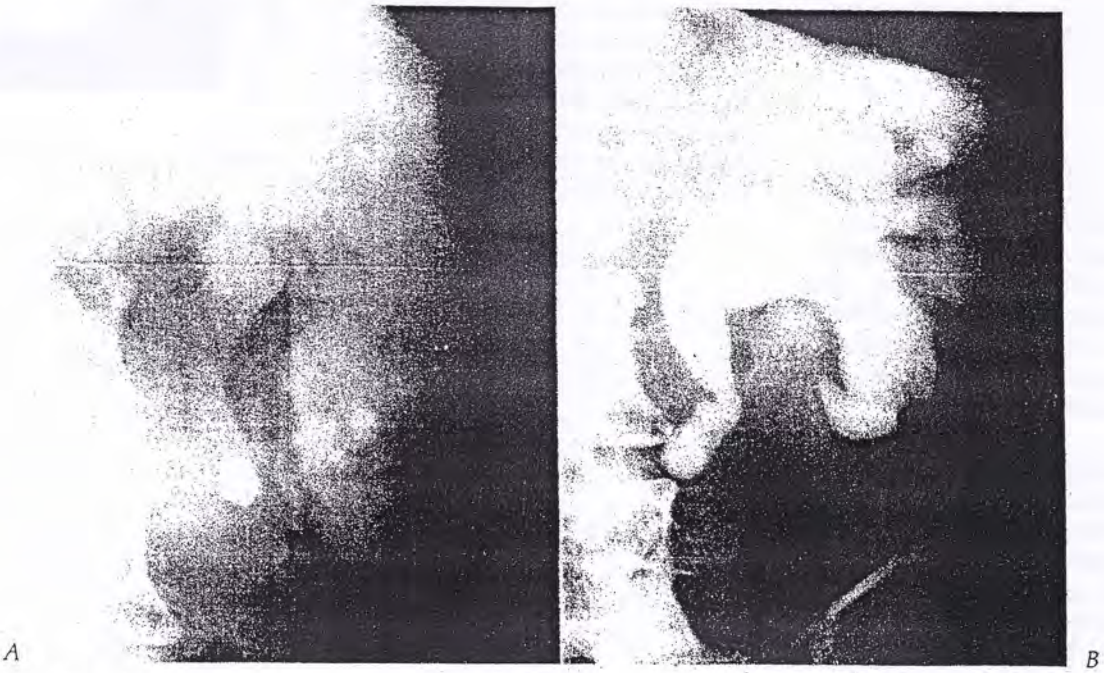


Fig. 9.16
(*A, B*) Patient 16 (plain film and excretory urogram).

PATIENT 17 (Fig. 9.17)

64-year-old male, anuric for 12 hours after flank pain on the right for 2 days. A plain film showed no calcified stones, but at ultrasonography both kidneys proved severely obstructed. The patient had a history of gout and hyperuricaemia. A percutaneous nephrostomy was established on both sides for emergency drainage. Urine was sterile and showed a constant pH 5.0; serum creatinine normalized within 24 hours.

M: The patient most probably has uric acid stones, which can be dissolved by oral alkalinization therapy. With the nephrostomies in place, the ureters are poorly perfused and dissolution only unreliable. The treatment of choice is therefore ESWL in situ and subsequent oral alkalinization therapy. The stone on the left could be localized with ultrasonography through the full bladder, but the stone on the right is probably difficult to visualize. Our treatment of choice would therefore be ESWL in situ with fluoroscopic stone localization using the nephrostomies for delineating the stones.

F: This patient should initially have bilateral percutaneous nephrostomies inserted. With the settling of any associated pain or pyrexia, antegrade pyelograms would then demonstrate the picture above; a non-opaque stone in the right ureter at the level of the transverse process of L-4, and a non-opaque calculus in the left ureter at the ureterovesical junction.

With the nephrostomy tubes performing an almost complete 'defunctioning' of the urinary tract, oral sodium bicarbonate would be unlikely to reach the stones and effect dissolution. It is also unwise to instil sodium bicarbonate through the nephrostomy tubes; this is unlikely to be successful and will probably cause pain. The stone on the left side is in the better position for treatment and should consequently be managed first. If piezoelectric lithotripsy is available, this would be easy to treat. In the absence of this form of lithotripsy, I would perform a ureteroscopy with ultrasonic fragmentation of the left ureteric stone. The calculus in the right ureter is in a relatively poor position for ESWL and so, at the same time as performing the ureteroscopy on the left stone, I would insert a double-pigtail stent in the right ureter and treat the patient with oral sodium bicarbonate after removing both of the nephrostomy tubes. I would then review the patient in 1 month's time with an intravenous urogram.

Both stones were disintegrated with ESWL in situ in one session, using fluoroscopic stone localization and dye administration via the nephrostomies; electromagnetic lithotripsy at 18–19 kV and 3500 impulses on the right and 2500 impulses on the left sufficed for complete disintegration of the stones. After 48 hours, urinary drainage was unobstructed on both sides and the nephrostomy tubes could be removed. Stone analysis: 100% uric acid. The patient was maintained on oral alkalinization therapy and allopurinol for another 3 months.

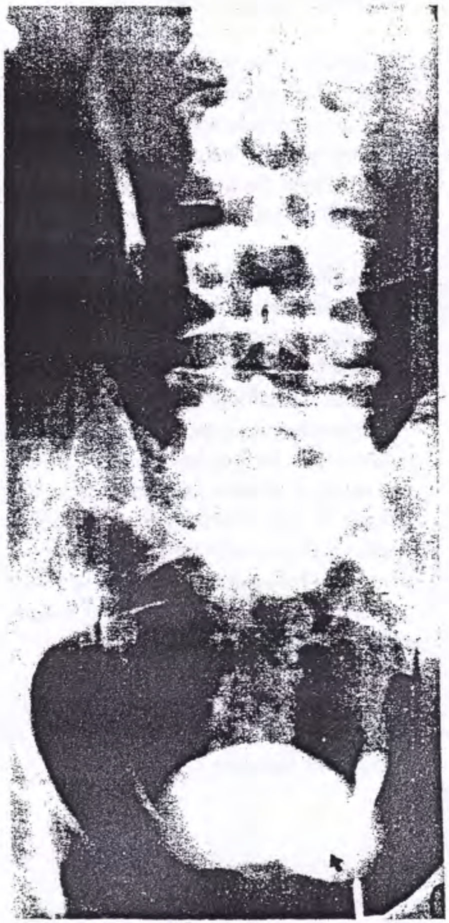


Fig. 9.17
Patient 17 (bilateral nephrostogram).

PATIENT 18 (Fig. 9.18)

74-year-old male with prostatic carcinoma treated by orchiectomy. In addition to symptoms of infravesical outflow obstruction, he had recurrent attacks of left flank pain for 3 weeks. Rectal palpation and ultrasonography demonstrated a T4 lesion and about 150 ml of residual urine. The urine was sterile; serum creatinine 1.7 mg/100 ml.

M: Ureteral stones impacted in the mid-ureter are usually difficult to focus; our experience with ESWL in situ with second generation lithotriptors of these stones has been rather disappointing, mainly due to the localization problem. We would primarily approach an impacted stone in the mid-ureter region overlying the bony pelvis by retrograde manipulation. If it cannot be dislodged easily with a catheter, we would resort to ureteroscopy and lasertripsy. With this patient's large prostate, retrograde access is probably impossible, so that an antegrade approach through a percutaneous nephrostomy with the flexible ureteroscope and laser, or electrohydraulic lithotripsy may be necessary.

F: The management of this stone is complicated by two factors: the patient has prostatic carcinoma, which would probably make transurethral access to the ureteric orifice difficult, and the position of the stone, which would make localization with ESWL difficult also. It is often said that stones which overlie the bony pelvis are easily treated by placing the patient in the prone position. My experience with this technique is less than satisfactory.

I would therefore adopt an antegrade approach, with percutaneous puncture of the middle group of calyces giving access to the pelviureteric junction and the passage of a flexible nephroscope down the dilated ureter to the stone. It might then be possible to engage the stone and bring it back into the kidney for direct percutaneous removal, or it may be possible to fragment the stone in situ with the electrohydraulic probe or the laser.

Retrograde ureteral manipulation failed because the ureteral orifice could not be visualized. Percutaneous access was therefore established through a lower pole calyx and the flexible 16 F nephroscope was inserted through the sheath of the 27 F nephroscope. It was advanced down to the stone and the stone was disintegrated with electrohydraulic lithotripsy. Larger fragments were removed with a basket, the smaller residual fragments passed without further symptoms within the following 14 days. Stone analysis: calcium-oxalate-dihydrate 62%, calcium-oxalate-monohydrate 16%, uric acid 12%.

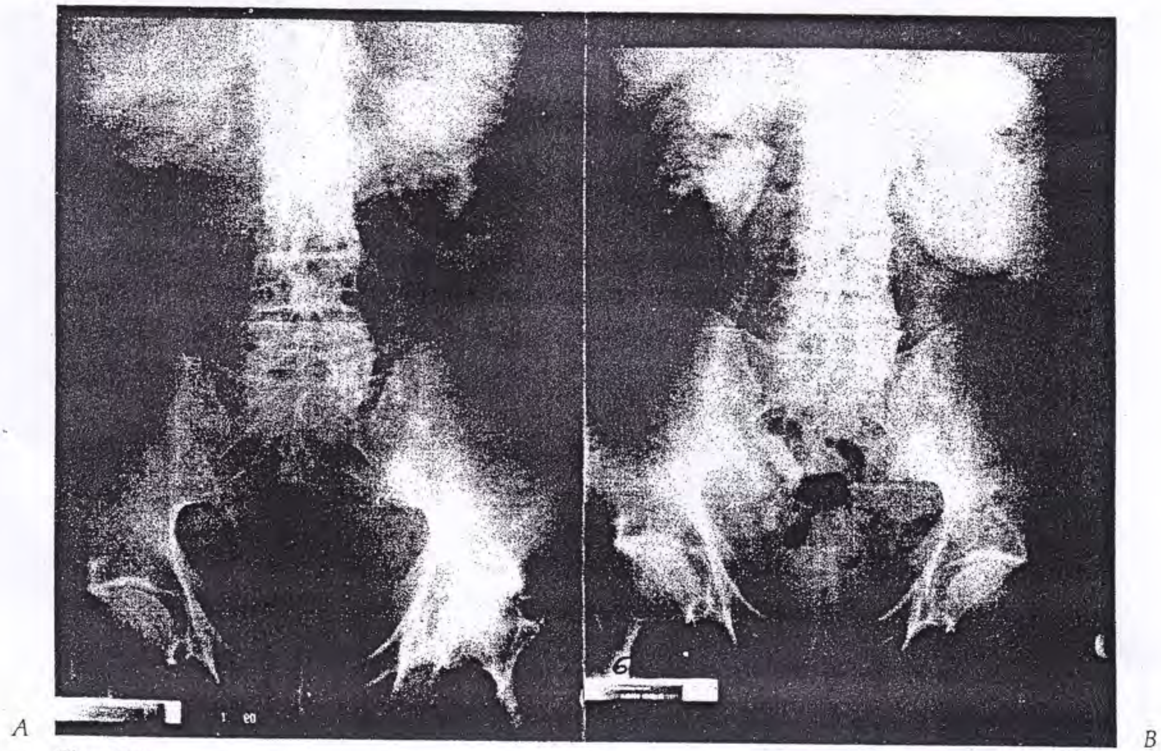


Fig. 9.18
(*A, B*) Patient 18 (plain film and delayed film of excretory urogram).

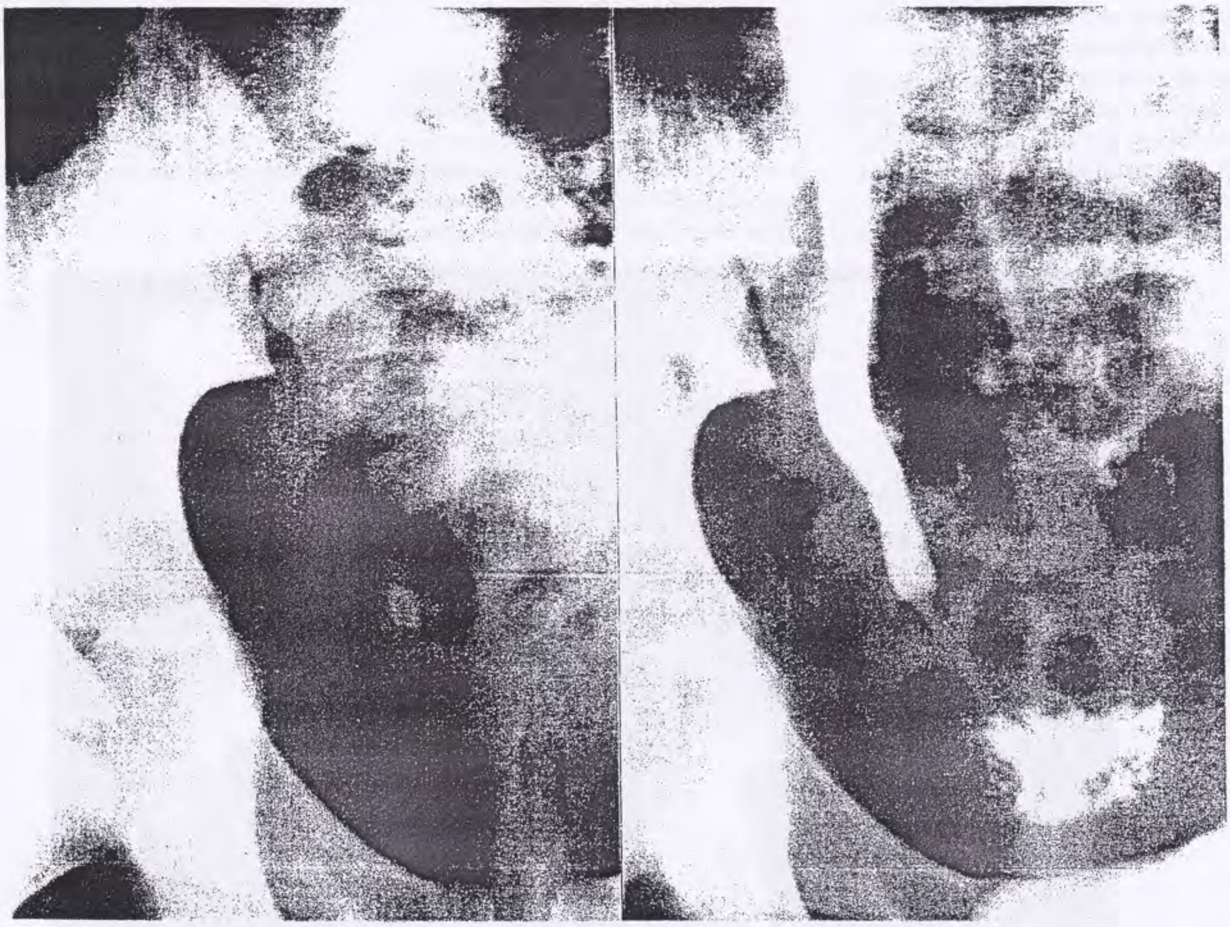
PATIENT 19 (Fig. 9.19)

3-year-old boy with unclear abdominal pain and haematuria. Ultrasonography showed an obstructed right kidney. The left upper tract and lower urinary tract were normal, the urine was sterile.

M: This stone may well pass eventually, but this would almost certainly cause considerable pain and might be associated with complications. If an ESWL system with a very small focal high-pressure zone and ultrasonic stone localization is available, I would recommend early ESWL in situ of the stone. With a system of this type, soft tissue trauma is minimized, as the high pressure is pinpointed to the stone. In children almost all ureteral stones can be visualized by ultrasonography, especially with dilated ureters.

F: This stone should be treated by ESWL. In the case of X-ray guided stone localization, the gonads should be well covered. A slight problem may exist with the positioning of a lower ureteric calculus, which, like this, is not very radio-opaque. The oblique X-ray monitor of the Siemens Lithostar, which would be looking at this through the pubic bone, might have difficulty localizing it. In the child, this may not be difficult to overcome, but in the adult it may cause problems.

The stone was treated with piezo-ESWL using continuous ultrasonic stone localization; no anaesthesia or analgesics were needed. 1500 impulses at grade 2 were administered. Fragments were passed within hours of the treatment. After 24 hours the tract was stone free and unobstructed.


A

B

Fig. 9.19

(*A, B*) Patient 19 (plain film and excretory urogram).

PATIENT 20 (Fig. 9.20)

20-year-old female who had a urological evaluation because of painless haematuria. No history of urinary tract infection or renal pain. The left upper urinary tract was normal, the urine sterile and blood pressure normal.

M: Whereas a calculus is frequently trapped in an orthotopic ureterocoele, this is rare in an ectopic ureterocoele in an adult, especially if the related upper renal moiety still shows some residual function. If this is confirmed by radioisotope renography, or by demonstrating good parenchyma at the upper pole, it would be justifiable to simply incise the ureterocoele so that a 12.5 F ureteroscope can be inserted. The stone is then disintegrated with ultrasonic, electrohydraulic, or laser lithotripsy and the fragments are removed endoscopically. The upper moiety will be refluxing, but as the urine is sterile there is a good chance that the patient will remain asymptomatic and that renal function will be unchanged. If the upper moiety does not seem salvageable, it should be removed by heminephroureterectomy, reimplantation of the ureter of the lower moiety and repair of the bladder wall.

F: In the first instance, I would treat this by endoscopic incision of the ureterocoele and litholapaxy. Subsequent follow up would reveal a degree of recovery of the upper renal moiety and indicate whether any further treatment was required.

All stones were removed by ultrasonic lithotripsy with the 12.5 F ureteroscope after incision of the ureterocoele. The patient was asymptomatic subsequently and refused all further treatment.

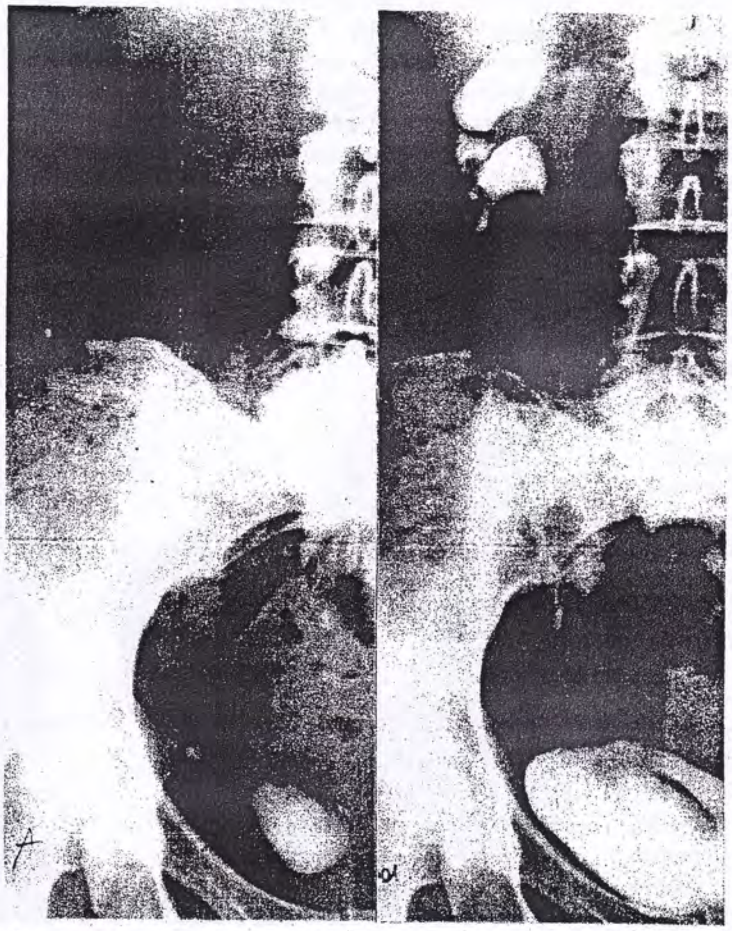

A B

Fig. 9.20
(*A, B*) Patient 20 (plain film and excretory urogram).

PATIENT 21 (Fig. 9.21)

64-year-old male, who had been subjected to open stone surgery of both kidneys previously. The last procedure on the right resulted in a non-functioning, atrophic kidney, so that the patient at first refused surgical treatment on the left when recurrent stones were again diagnosed 2 years previously. He subsequently experienced dysuria from chronic urinary infection, but it was not until a severe myocardial infarction 3 months previously that deterioration of renal function was noted. In spite of a ventricular aneurysm, the patient was referred for stone removal because his endogenous creatinine clearance had dropped to 26 ml/minute from almost normal levels within a 3-month period. The patient was afebrile and had no hypertension, but the urine was infected with Proteus mirabilis.

M: The main reason for the acute deterioration of renal function would seem to be the stone impacted above a segment of ureter scarred by previous surgery. To secure urinary drainage, I would insert a thin percutaneous nephrostomy through the lower pole and then try to fragment the ureteral stone by ESWL in situ. If this fails, I would attempt removal of the stone by antegrade or retrograde endoscopic manoeuvres. The partial staghorn stone in the upper pole should only be attacked after the ureteral problem is solved and renal function has been stabilized. It should be accessible to percutaneous nephrolithotripsy.

F: I would attempt initial debulking of the staghorn calculus by inserting a percutaneous track through the middle calyx with fragmentation of as much of this stone as possible. The stone in the ureter and any remaining fragments in the kidney would then be amenable to ESWL, with the large nephrostomy tube providing adequate renal drainage.

An 8 F nephrostomy tube was inserted into the left collecting system through the lower pole. The ureter could not be entered retrogradely or antegradely because of an S-shaped kink just below the stone. The latter was therefore treated with electromagnetic ESWL in situ, but in spite of four sessions with a total of 12 000 shocks at 18–18 kV, about one-third of it remained intact. Although all other fragments were rapidly passed and the nephrostomy functioned without problems, the patient had recurrent attacks of fever and septicaemia and his serum creatinine clearance deteriorated to 4.6 mg/dl. *Candida* and *Proteus* were repeatedly cultured in blood cultures, in spite of appropriate antimicrobial treatment at a dosage monitored by serum levels. An attempt at antegrade ureteroscopy with the flexible ureteroscope failed, because the ureter was so embedded in scar tissue that the stone could not be reached; thinner rigid instruments could likewise not be advanced. The procedure had to be terminated because of perforation of the renal pelvis on its medial aspect. Endoscopic antegrade manipulation was again attempted through the same tract 1 week later, but this time the collecting system was perforated during the tract dilatation and severe haemorrhage occurred. The tract was tamponaded with a large nephrostomy tube, but there was continuous haemorrhagic ooze. Immediate embolization or surgical exploration of the kidney were planned, but before this could be performed the patient had a sudden cardiac arrest and died. The autopsy demonstrated recurrent myocardial infarction, but also severe perirenal scarring with almost complete atrophic destruction of the lower pole, and an acute rupture of the basilar segmental artery as the source of haemorrhage. In retrospect, open surgical correction of the multitude of problems in one session would probably have been the safer approach.

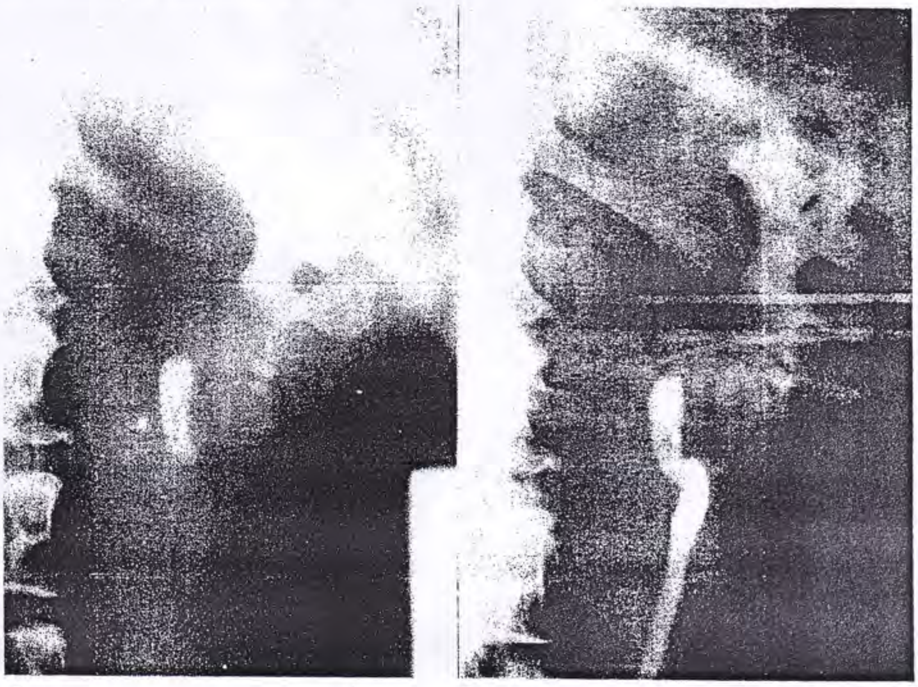

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Fig. 9.21
(*A, B*) Patient 21 (plain film and retrograde ureteropyelogram).

Chapter 10

Pathophysiology of nephrolithiasis

C Y C Pak

Introduction

The recent introduction of nephrostolithotomy and extracorporeal shock wave lithotripsy has revolutionized the treatment of nephrolithiasis (Chaussy et al 1980). Most stones can now be removed with greater ease and less morbidity.

While overshadowed by the above advances, there has been an equally notable progress in the medical arena. This progress has encompassed three closely linked, interdependent areas – pathophysiological elucidation, diagnostic separation and medical prevention of recurrent nephrolithiasis. It is now known that the stone-forming urinary environment is characterized by an altered biochemical-physicochemical picture originating from metabolic or environmental disturbances (Pak et al 1985c). On the basis of these physiological derangements, it has been possible to formulate a scheme for diagnostic separation (Pak et al 1980a). This improved identification of the cause for nephrolithiasis has led to the selection of optimum medical treatment programmes designed to inhibit further stone formation (Pak et al 1981b). It is now possible to identify the cause of stone formation in the vast majority of patients (Pak 1988) and to inhibit new stone formation in most patients (Preminger et al 1985a).

Despite dramatic progress in both surgical and medical areas, there has been an unfortunate tendency to promote one approach while disparaging or ignoring the other. It should be clear that the two approaches are complementary, and that the ultimate control of nephrolithiasis mandates a conscious application of both approaches.

This chapter will provide justification of medical diagnosis and management in the current setting of facilitated methods of stone removal. It shall then consider pathophysiology of different causes of stone formation. Chapter 11 will present various diagnostic protocols applicable to evaluation of single stone-formers, those with active recurrent stone formation and of patients undergoing removal of existing stones. Chapter 12 will give an outline of selective treatment programmes, with a resume of rationale, indication and practical guidelines for each medical prophylactic regimen.

JUSTIFICATION FOR MEDICAL DIAGNOSIS AND MANAGEMENT

The advent of improved methods of stone removal with nephrostolithotomy (Segura et al 1983) and extracorporeal shock wave lithotripsy (Chaussey et al 1980) has led some physicians to disregard the need for medical diagnosis and treatment. There are compelling reasons to dispel this notion.

First, there is a fundamental difference between the objective of a medical approach and that of surgical approach. The former is the prevention of recurrent stone formation; the latter is the removal of existing stones. Nephrolithiasis is a disease characterized by recurrent stone formation. Once a person has formed a stone, the possibility for that person to form more stones is great, approaching 67–100% (Blacklock 1965; Williams 1963; Coe et al 1977). A successful facilitated removal of existing stone(s) by nephrostolithotomy or extracorporeal shock wave or piezoelectric lithotripsy does not guarantee prevention of subsequent new stone formation. Thus, the application of surgical approach alone does not obviate the problem of recurrence (Table 10.1).

Second, not all stone episodes require intervention for removal of stones. In one of our series (Pak et al 1985a), 89 patients had an average of 4.34 stone episodes/year during 3 years immediately prior to institution of a selective medical therapy. However, most of these stone episodes were resolved with a spontaneous stone passage. Surgery was required in only 5.3% of cases. Even with a wider application of extracorporeal shock wave lithotripsy, it is expected that a substantial number of stone episodes would have spontaneous resolution. Application of an effective medical treatment programme could prevent stone recurrences not amenable to surgical treatment.

Third, stone episodes are often associated with a severe renal colic. Even when amenable to correction by newer methods of stone removal, there is often a lag time between the onset and removal when the afflicted patients may be exposed to severe suffering. By preventing recurrence, an effective medical therapy could reduce this morbidity.

Fourth, a successful medical treatment programme may greatly reduce the need for stone surgery. In patients undergoing long-term treatment (Pak et al 1985a) with potassium citrate, none has yet required surgery for the removal of newly formed stones. In our overall series of patients undergoing various long-term selective treatment programmes, the need for surgery was markedly reduced to 2% (Preminger et al 1985a).

Table 10.1 Justification of medical approach

	Medical approach	Surgical approach
Prevention of recurrence	Yes	No
Prevention of spontaneous passage	Yes	No
Avoidance of renal colic before stone removal	Yes	No
Reduced need for stone removal	Yes	No
Correction of extrarenal manifestations	Yes	No
Long-term compliance	Essential	Unnecessary
Side effects of medication	Present	Absent
Initial diagnosis and follow-up	Essential	Unnecessary

Fifth, medical treatment could potentially correct extrarenal manifestations of the stone disease, whereas surgical approach concentrates on stone removal alone. Some forms of nephrolithiasis represent a multisystem disease in which stone formation is only one manifestation. In renal hypercalciuria with secondary hyperparathyroidism, there may be skeletal involvement, as indicated by a reduced bone density noted on photon absorptiometry (Lawoyin et al 1979). Thiazide therapy may restore normal parathyroid function and avert this complication, as shown by stable calcium balance and bone density during long-term follow-up (Pak et al 1982). Primary hyperparathyroidism is manifested clinically by peptic ulcer disease and bone disease, as well as by nephrolithiasis. Parathyroidectomy typically averts all three complications. Hypokalaemia and bone disease may complicate the course of renal tubular acidosis. Treatment with potassium citrate could prevent these complications (Preminger et al 1985b). This treatment has been shown to improve calcium balance by increasing intestinal calcium absorption and reducing calcium excretion. In chronic diarrhoeal syndrome, nephrolithiasis occurs secondarily from primary bowel disease. Bone disease may also be present from the acquired metabolic acidosis and intestinal malabsorption particularly of calcium. The treatment directed at the underlying bowel disease and acidosis may produce amelioration of extrarenal manifestations as well as nephrolithiasis. Gouty diathesis may present, not only with renal stones composed of uric acid and/or calcium oxalate, but also with arthritic manifestations. Treatment with allopurinol and potassium citrate may produce improvement in both gout and nephrolithiasis (Pak et al 1986). In contrast, it is not expected that removal of stone(s) alone would favourably affect any of the extrarenal manifestations previously enumerated.

Despite these potential advantages of the medical approach, certain inherent problems of a medical treatment programme should not be overlooked. To be effective, the medical prevention programme requires a rigid compliance by the patient and constant surveillance by the physician. It demands commitment by the patient to adhere to the chosen programme on a daily continuing basis for an extended period of time (of up to many years). A regular follow-up evaluation by the physician is critical to assure that the response is appropriate.

Moreover, all medical treatments carry certain hazards, especially if they are misused. Thus, in order to minimize complications of therapy, a careful diagnostic separation and the selection of an optimum treatment programme are essential.

The advantages of a medical approach should be carefully weighed against its disadvantages on an individual basis for each patient before a decision is made for medical diagnostic separation and treatment. Factors favouring the adoption of the medical approach might be presence of active stone disease with frequent recurrence and coexistence of extrarenal manifestations. On the other hand, a medical approach may be impractical in persons with disdain for medications, especially when their stone disease is not severe.

METABOLIC CLASSIFICATION OF NEPHROLITHIASIS

Nephrolithiasis may be characterized on the basis of underlying physiological derangements (Pak 1985) (Table 10.2). The term 'metabolic classification', though widely used, is strictly a misnomer, since physiological disturbances could result from environmental factors as well as from metabolic factors (of hormonal or genetic origin). This classification has been formulated on the basis of available data. It will require modification as further pathogenetic factors are elucidated. Moreover, this classification is based on the presumed principal physiological abnormality. It also recognizes that other disturbances may coexist in a given disorder.

Table 10.2 Classification of nephrolithiasis

Calcareous renal calculi	
Hypercalciuria:	Absorptive Renal Resorptive Other
Hyperuricosuria:	Primary urate overproduction Dietary purine overindulgence
Hyperoxaluria:	Primary Secondary
Inhibitor deficiency:	Hypocitraturia Other
Low urinary pH:	Gouty diathesis Other
Low urine volume	
No physiological disturbance	
Non-calcareous renal calculi	
Low urinary pH:	Uric acid stones
Cystinuria:	Cystine stones
Infection with urea splitting organisms:	Struvite stones
Other	

PATHOGENETIC SIGNIFICANCE OF PHYSIOLOGICAL DERANGEMENTS

The above classification assumes that the implicated physiological distrubances are pathogenetically important in stone formation (Table 10.3).

Hypercalciuria

The importance of hypercalciuria in calcium stone formation is well known. First, it increases saturation of urine with respect to stone-forming calcium salts. Our studies have disclosed a direct correlation between urinary saturation of calcium oxalate, or brushite, and urinary calcium concentration (Fig. 10.1) (Pak & Holt 1976). Despite reports to the contrary, an induced hypercalciuria from a high calcium intake invariably increases the urinary saturation of calcium salts (Harvey et al 1985). Second, hypercalciuria reduces the inhibitor activity in urine against the crystallization of calcium salts by binding certain negatively charged inhibitors and inactivating them (Zerwekh et al 1988). In 11 patients with stones of mixed aetiology maintained on a constant metabolic diet and fluid intake, calcium gluconate (200 mg calcium three times/day) significantly reduced the formation product ratio (limit of metastability) of calcium oxalate from 11.18 to 9.60 ($P < 0.005$). Third, persistent hypercalciuria is one of the most important determinants for continued stone formation during therapy (Strauss et al 1982). Finally, the correction of hypercalciuria by thiazide (Yendt & Cohanim 1978) or sodium cellulose phosphate (Pak et al 1974a) have been shown to produce amelioration of stone disease.

Table 10.3 Pathogenetic significance of physiological derangements in stone formation

Physiological derangement	Physicochemical effect in urine
Hypercalciuria	Increased saturation of calcium salts Attenuation of inhibitor activity
Hyperuricosuria	Increased saturation of monosodium urate Facilitated urate-induced crystallization of calcium oxalate
Hyperoxaluria	Increased saturation of calcium oxalate
Hypocitraturia	Increased saturation of calcium salts from reduced calcium complexation by citrate Reduced inhibitor activity against spontaneous precipitation, crystal growth and agglomeration
Low urinary pH	Low uric acid solubility Uric acid-induced crystallization of calcium oxalate
Low urine volume	Increased saturation of stone-forming salts

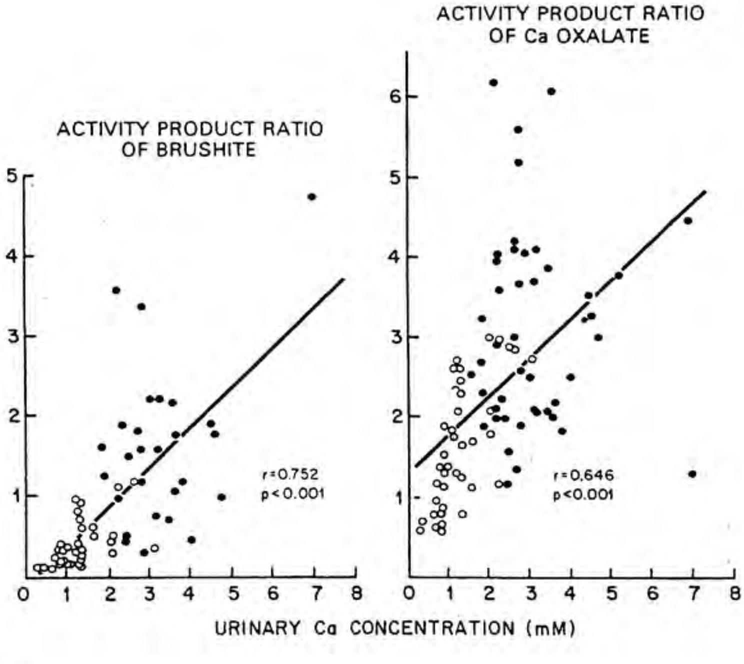

Fig. 10.1

Dependence of urinary saturation (activity product ratio) of calcium salts on the urinary concentration of calcium. Open circles represent values from control subjects without stones and solid circles those with patients with calcium nephrolithiasis. Regression lines are shown.

Hyperuricosuria

Recurrent calcium nephrolithiasis can occur in subjects with hyperuricosuria with no other discernible cause of nephrolithiasis and with normal urinary pH (> 5.5). The following scheme has been proposed (Pak et al 1979). The urinary environment may be supersaturated with respect to monosodium urate because of a high urinary content of uric acid and a favourable urinary pH ($> pK_a$ for the first proton of uric acid of 5.47), in which adequate dissociation of uric acid occurs. Either a colloidal or crystalline monosodium urate could theoretically form in such an environment. It can then initiate the crystallization of calcium oxalate by direct induction of heterogeneous nucleation of calcium oxalate or by removing urinary macromolecules through adsorption thereby attenuating their inhibitor activity (Zerwekh et al 1983).

This scheme is supported by studies using artificial monosodium urate and naturally-occurring urinary macromolecules. Moreover, the induction of hyperuricosuria by oral purine loading has been shown to facilitate spontaneous precipitation of calcium oxalate in urine, providing further credence to this scheme (Pak et al 1978). Unfortunately, the presence of colloidal or crystalline monosodium urate in urine has not been conclusively demonstrated, and the role of monosodium urate in heterogeneous nucleation has not been consistently found. The role of uric acid (Coe 1980), which may be similar to that of monosodium urate, will be discussed under the heading Low urinary pH.

Hyperoxaluria

Hyperoxaluria probably contributes to calcium stone formation by rendering the urine more supersaturated with respect to calcium oxalate. It has been suggested that hyperoxaluria exerts a more prominent effect on stone formation than hypercalciuria. In a typical urinary environment, some of the total calcium and oxalate exist as soluble complexes. Thus, a rise in urinary calcium concentration (from hypercalciuria) might cause only a modest increase in urinary saturation (activity product) of calcium oxalate, because the increased activity of calcium is partly opposed by the decline in oxalate activity resulting from calcium-to-oxalate complexation. However, it has been suggested that an elevation in urinary oxalate concentration (from hyperoxaluria) might produce a more prominent rise in urinary saturation of calcium oxalate, because of a less modest decline in calcium activity from complexation (Nordin et al 1972). The above conclusion could not be confirmed when soluble complexes were calculated using stability constants for calcium determined at physiological temperature rather than at room temperature (Pak et al 1982). Under these conditions, a rise in calcium concentration is as effective as an increase in oxalate concentration in raising the activity product of calcium oxalate.

Hypocitraturia

Hypocitraturia probably represents an important risk for the formation of calcium stones based on the known capacity of citrate to inhibit the crystallization of stone-forming calcium salts. Citrate reduces urinary saturation of calcium oxalate or calcium phosphate by forming a soluble complex with calcium and thereby reducing calcium ion activity (Pak et al 1982). Although citrate is an effective inhibitor of calcium phosphate crystal growth (Bisaz et al 1978), it has only a modest inhibitor activity against calcium oxalate crystal growth (Meyer & Smith 1975). Moreover, citrate directly inhibits spontaneous nucleation of calcium oxalate (Nicar et al 1987). Citrate is also a potent inhibitor of the agglomeration of calcium oxalate crystals (Kok et al 1986).

Other simple (small molecular weight) and complex (macromolecular) inhibitors of the crystallization of calcium salts have been identified in urine, including pyrophosphate (Fleisch & Bisaz 1962), glycopeptides (Kitamura et al 1981), glycosaminoglycans (Bowyer et al 1979), ribonucleic acids and glycoproteins (or nephrocalcin) (Nakagawa et al 1983). There is some evidence that the renal excretion of these substances may be disturbed in certain patients with nephrolithiasis; however, this suggestion has not been fully substantiated. A recent finding that a particular glycoprotein from patients with calcium nephrolithiasis may be abnormal structurally and functionally is most intriguing, but requires substantiation (Nakagawa et al 1985). It is expected that these inhibitors may have diagnostic utility, if methods could be developed for simple and reliable assays. They may have clinical relevance if therapeutic approaches could be found for augmenting the amount or the activity of these inhibitors in urine.

Low urinary pH

Persistent passage of unusually acid urine (pH < 5.5) may cause both uric acid and calcium stones. Because urinary pH is close to, or less than, the dissociation constant of uric acid, the concentration of undissociated uric acid is high, leading to uric acid crystallization (Pak et al 1977, Pak et al 1986). The uric acid so-formed may cause the crystallization of calcium oxalate by the same mechanisms described for monosodium urate (Coe 1980). Although uric acid is less efficient than monosodium urate in inducing heterogeneous nucleation of calcium oxalate, its crystalline dimensions are more compatible with epitaxy (crystalline overgrowth of calcium oxalate). Moreover, uric acid has been shown to remove naturally occurring, urinary macromolecular inhibitors, thereby attenuating their activity (Zerwekh et al 1983).

Low urine volume

Low urine volume contributes to stone formation by increasing the concentration of stone-forming constituents and raising the saturation of stone-forming salts (Pak et al 1980b). Volume changes affect both cationic and anionic components (e.g. calcium and oxalate), contributing to the saturation of a given stone-forming salt (e.g. calcium oxalate). Thus, a reduction in urine output by one-half generally increases urinary saturation by more than two-fold. Therefore, a marked urinary supersaturation may occur from reduced urine output even when the total renal excretion of stone-forming constituents is normal.

Cystinuria

Since there are no known inhibitors of the crystallization of cystine, cystine stone formation is dictated primarily by the urinary supersaturation of cystine. Thus, cystine stones could theoretically form whenever urinary cystine concentration exceeds the solubility limit. Dent & Senior (1955) established the solubility of cystine as approximately 300 mg/litre at pH 5, increasing to 400 mg/litre at pH 7 and 500 mg/litre at pH 7.5. However, our recent study indicates that the cystine solubility curve needs to be redefined (Pak & Fuller 1983). The solubility for cystine in individual urine samples varied considerably, being influenced by the amount of electrolytes and macromolecules. In general, the actual cystine solubility in urine was considerably lower than that described by Dent & Senior and ranged from 170–300 mg/litre at pH 5.0, 190–400 mg/litre at pH 7.0 and 220–500 mg/litre at pH 7.5. Thus, the minimum cystine concentration required to elicit stone formation is lower than previously believed.

High urinary pH

A high urinary pH (neutral or alkaline) favours the formation of calcium phosphate stones, especially if urinary calcium concentration is high, because of the increased dissociation of phosphate and elevated concentration of trivalent phosphate ion. If a high concentration of ammonium ion is also present (e.g. from infection with urea-splitting organisms), urinary environment may become supersaturated with respect to struvite (magnesium ammonium phosphate) (Griffith & Musher 1973). The main determinant for struvite crystallization is the supersaturated state, since no inhibitors are known to influence this process.

PATHOPHYSIOLOGY OF PHYSIOLOGICAL DERANGEMENTS—PATHOPHYSIOLOGY OF HYPERCALCIURIA

The exact cause for the hypercalciuria associated with nephrolithiasis is uncertain, although its association with recurrent calcium nephrolithiasis has long been recognized. The term 'idiopathic hypercalciuria' has been used to denote this entity. One prevailing theory considers idiopathic hypercalciuria to consist of several entities of separate pathogenetic origin (Pak 1979, Pak 1986) (Fig. 10.2).

Absorptive hypercalciuria (type I and type II)

The basic abnormality is absorptive hypercalciuria is the intestinal hyperabsorption of calcium (Fig. 10.2). The consequent increase in the circulating concentration of calcium enhances the renal filtered load and suppresses parathyroid function. Hypercalciuria ensues from the increased filtered load and the reduced tubular reabsorption of calcium consequent to parathyroid suppression.

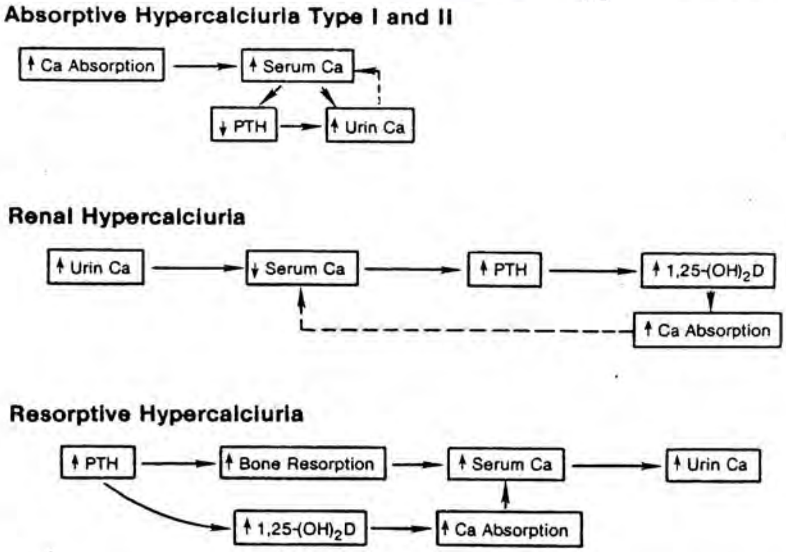

Fig. 10.2

Schemes for absorptive hypercalciuria type I and type II, renal hypercalciuria and resorptive hypercalciuria. Dashed line indicates compensatory inhibition.

The excessive renal loss of calcium compensates for the high calcium absorption from the intestinal tract and helps to maintain serum calcium in the normal range. This entity excludes those with renal phosphate leak or excessive vitamin D [1,25-$(OH)_2D$] production (to be discussed separately under Fasting hypercalciuria without parathyroid stimulation).

In one form (type I), high urinary calcium (relative to normal urinary calcium at the same calcium intake) is found during both low and high calcium intakes, whereas in another form (type II), hypercalciuria occurs only during a high calcium intake. Sometimes called 'dietary hypercalciuria', absorptive hypercalciuria type II may represent a less severe form of the type I presentation. Both presentations may be seen in the same patients during the course of their disease.

The exact cause for the enhancement of intestinal calcium absorption is not known. It may be a primary jejunal disease (Brannan et al 1979, Pak et al 1985b), since the high calcium absorption has been disclosed only in the jejunum, and the absorption of magnesium and phosphate has been shown to be normal. The primary nature of this disturbance is indicated by persistence of intestinal hyperabsorption of calcium during treatment with adrenocorticosteroids (which lowers intestinal calcium absorption in sarcoidosis) (Zerwekh et al 1980), thiazide (which lower urinary calcium) (Zerwekh & Pak 1980) and orthophosphate (which reduces serum concentration of 1,25-$(OH)_2D$ (Barilla et al 1979). Moreover, this disturbance appears to be inherited as an autosomal dominant trait (Pak et al 1981a). Recently, an experimental model of this syndrome has been produced in inbred hypercalciuric rats (Bushinsky et al 1987).

There is no evidence that the skeleton is adversely affected in this condition. Normal values have been reported for serum osteocalcin, alkaline phosphatase activity, urinary hydroxyproline and bone density in the radius (shaft) and lumbar vertebrae (Pak 1986). No clinically evident bone disease has been attributed to absorptive hypercalciuria. Calcium conservation is intact even when the intestinal calcium absorption is reduced by sodium cellulose phosphate. The absorbed calcium (lumen-blood) exceeds urinary calcium commensurate with the estimated net secreted calcium.

In patients with documented absorptive hypercalciuria type I or type II, evidence for a 'primary' renal calcium leak is lacking. Fasting urinary calcium may be *secondarily* increased in patients with absorptive hypercalciuria from the primary enhancement of intestinal calcium absorption. If the duration of fast is inadequate and the absorbed calcium is incompletely cleared by the kidneys, the high calcium absorption may cause fasting hypercalciuria by increasing the renal filtered load of calcium and by suppressing parathyroid function, thus impairing renal tubular reabsorption of calcium (Pak & Galosy 1979). In these patients with absorptive hypercalciuria, fasting hypercalciuria would not be accompanied by parathyroid stimulation, unlike in those with renal hypercalciuria.

There is normally an inverse relation between fasting urinary calcium and cyclic AMP (Pak & Galosy 1979). This relation may have physiological relevance, since it may reflect varying degrees of intestinal calcium absorption among subjects and differing amounts of absorbed calcium remaining in the circulation to influence parathyroid function. Thus, an incomplete clearance of absorbed calcium would lead to a higher value for fasting urinary calcium, and a lower value for cyclic AMP (since some of the absorbed calcium would be left in circulation to suppress parathyroid function). For normal subjects, the regression line (between fasting urinary calcium and cyclic AMP) and 95% confidence limits have been defined. Most of the values in absorptive hypercalciuria were within these normal limits, though toward higher fasting urinary calcium and lower cyclic AMP. This result suggests that relative fasting hypercalciuria of absorptive hypercalciuria is due to the incomplete clearance of absorbed calcium, a situation which is more likely to develop in this condition because of high intestinal calcium absorption, rather than to a primary renal calcium leak.

Moreover, in patients with absorptive hypercalciuria who presented with fasting hypercalciuria, fasting urinary calcium decreased and urinary cyclic AMP increased toward more normal ranges (but not above normal) when the amount of absorbed calcium was reduced by inhibition of intestinal calcium absorption with sodium cellulose phosphate (Pak & Galosy 1979). The results suggest that the renal leak of calcium acquired from parathyroid suppression in these patients is corrected by a restoration of normal parathyroid function from a more complete removal of absorbed calcium. A lack of a generalized disturbance in renal proximal tubular function is shown by normal calciuric response to carbohydrate load (Barilla et al 1978), and by normal natriuretic response to thiazide (Sakhaee et al 1985).

Renal hypercalciuria

The pathogenetic scheme and physiological manifestations of renal hypercalciuria are distinct from those of absorptive hypercalciuria (Pak 1979) (Table 10.4).

The primary abnormality in renal hypercalciuria is believed to be the impairment of the renal tubular reabsorption of calcium (Fig. 10.2). The consequent reduction in the circulating concentration of calcium stimulates parathyroid function. There may be an excessive mobilization of calcium from bone and an enhanced intestinal absorption of calcium because of the parathyroid hormone (PTH) excess and the ensuing stimulation of the renal synthesis of 1,25-(OH)$_2$D. These effects restore serum calcium toward normal. Unlike primary hyperparathyroidism, serum calcium is normal, and the state of hyperparathyroidism is secondary.

The occurrence of a primary renal calcium leak is shown by fasting hypercalciuria, which is poorly corrected by sodium cellulose phosphate and which is associated with parathyroid stimulation (Pak & Galosy 1979).

The concept that the fundamental defect in renal hypercalciuria is a proximal tubular dysfunction is supported by the response to thiazide (Sakhaee et al 1985) and carbohydrate (Barilla et al 1978). When thiazide is given to block reabsorption of calcium and sodium in the distal (renal) tubule, impaired proximal tubular function would be manifest as an exaggerated renal excretion of these cations. In our study, the exaggerated natriuretic and calciuric response to hydrochlorothiazide was encountered only in patients with documented renal hypercalciuria with secondary hyperparathyroidism (Sakhaee et al 1985).

Ingestion of readily metabolizable carbohydrate (without calcium) normally augments renal calcium excretion, believed to be due to an alteration in renal proximal tubular function (Lemann et al 1969). An exaggerated calciuric response to 100 g of glucose was encountered in patients with renal hypercalciuria with secondary hyperparathyroidism, not in those with absorptive hypercalciuria (Barilla et al 1978).

It has been suggested that renal calcium leak is secondary to an excessive dietary intake of sodium (Muldowney et al 1982). However, institution of a low sodium intake (9 mEq/day) did not eliminate fasting hypercalciuria in patients with renal hypercalciuria (unpublished observations).

The presence of parathyroid stimulation is critical for the diagnosis of renal hypercalciuria. The lack of hyperparathyroidism in some reports has led to the suggestion that renal hypercalciuria does not exist, or that it coexists with absorptive hypercalciuria (Coe et al 1982). However, there is unequivocal evidence for high serum PTH and/or urinary cyclic AMP in some patients with normocalcemic hypercalciuric nephrolithiasis (Coe et al 1973, Pak 1979, Pak et al 1974b, Pak et al 1980a). The absence of parathyroid stimulation could be due to the residual suppressive effect of excessively absorbed calcium on PTH secretion. When this effect was excluded by correcting serum PTH by the corresponding level of fractional intestinal calcium absorption, the resulting values (ratio of PTH and calcium absorption) were significantly higher in patients with renal hypercalciuria and control subjects (Pacifici et al 1985). Moreover, the restoration of normal intestinal calcium absorption by sodium cellulose phosphate may 'unmask' secondary hyperparathyroidism, since serum PTH may increase to above normal without a substantial reduction in fasting urinary calcium (Pak & Galosy 1979).

The scheme for renal hypercalciuria dictates that 1,25-(OH)$_2$D synthesis is enhanced from parathyroid stimulation and that intestinal calcium absorption is high due to 1,25-(OH)$_2$D excess (Pak 1979). Experimental verification is now available for this contention. Serum concentration of 1,25-(OH)$_2$D is high in renal hypercalciuria. The correction of renal calcium leak by thiazide restores normal serum 1,25-(OH)$_2$D and fractional intestinal calcium absorption,

Table 10.4 Physiological features of absorptive and renal hypercalciuria

Item	Absorptive hypercalciuria type I or type II	Renal hypercalciuria
Renal Ca leak	Secondary	Primary
Effect of sodium cellulose phosphate	Correctable	Non- or partly correctable
Natriuretic response to thiazide	Normal	Exaggerated
Calciuric response to carbohydrate	Normal	Exaggerated
Parathyroid function	Normal	Stimulated
Intestinal Ca absorption	Primarily increased	Secondarily increased
Site affected	Jejunum	Unknown
Dependence on 1,25-(OH)$_2$D	No correlation	Correlated
Response to thiazide	No change	Decreased
Skeletal status		
Bone density	Normal	Decreased/normal
Ca balance	Normal	Normal/negative

commensurate with the correction of hyperparathyroidism (Zerwekh & Pak 1980).

Although clinical bone disease is rare, bone density as measured by photon absorptiometry in the distal third of the radius is reduced in the group with renal hypercalciuria (as compared with age- and sex-matched controls) (Lawoyin et al 1979). These results indicate that secondary hyperparathyroidism exerts deleterious effects on the skeleton. The lack of a more serious involvement is probably due to the compensatory intestinal hyperabsorption of calcium that results from the PTH-induced renal synthesis of 1,25-$(OH)_2D$. This compensation is often inadequate, since urinary calcium usually exceeds absorbed calcium indicative of negative calcium balance.

Resorptive hypercalciuria

Resorptive hypercalciuria is characterized by primary hyperparathyroidism (Fig. 10.2). The initial event is excessive resorption of bone resulting from hypersecretion of PTH. Intestinal absorption of calcium is frequently elevated, because of PTH-dependent stimulation of renal synthesis of 1,25-$(OH)_2D$ (Kaplan et al 1977). These effects increase the circulating concentration and the renal filtered load of calcium. The occurrence of hypercalciuria in primary hyperparathyroidism seems paradoxical, since the primary renal effect of PTH is to stimulate tubular reabsorption of calcium. However, hypercalciuria is often encountered in primary hyperparathyroidism because PTH-dependent augmentation of renal tubular reabsorption of calcium is 'overcome' by an increase in the renal filtered load and by a suppressive effect of hypercalcaemia on calcium reabsorption.

Although the overall scheme for resorptive hypercalciuria in primary hyperparathyroidism is generally accepted, the mechanisms by which intestinal calcium absorption is controlled need to be elucidated. The high intestinal calcium absorption is customarily ascribed to the enhanced PTH-dependent synthesis of 1,25-$(OH)_2D$ (Kaplan et al 1977). Thus, the fractional calcium absorption bears a direct relationship with serum 1,25-$(OH)_2D$. However, in some patients with primary hyperparathyroidism, the intestinal hyperabsorption of calcium persists after parathyroidectomy, despite restoration of normal serum 1,25-$(OH)_2D$ (Bone et al 1979). The results suggest that factors other than 1,25-$(OH)_2D$ contribute to the maintenance of high intestinal calcium absorption in some hyperparathyroid patients in the postoperative state.

Fasting hypercalciuria without parathyroid stimulation

In some patients with normocalcaemic hypercalciuric nephrolithiasis, the diagnosis of absorptive or renal hypercalciuria cannot be made with certainty (Pak et al 1980a). This unclassified hypercalciuria is largely represented by fasting hypercalciuria without parathyroid stimulation. This picture points to neither absorptive hypercalciuria nor renal hypercalciuria. The lack of hyperparathyroidism suggests the diagnosis of absorptive hypercalciuria, but fasting urinary calcium is high. The fasting hypercalciuria indicates that a renal leak of calcium is present; however, secondary stimulation of parathyroid function is lacking.

This ambiguous presentation has led to the notion that 'true' absorptive and renal hypercalciurias do not exist. However, there is little doubt in our minds that these conditions exist as separate and distinct entities (as previously discussed).

The percentage of patients with hypercalciuric nephrolithiasis who have fasting hypercalciuria, but no parathyroid stimulation, varies considerably among available reports, ranging from 10–69% (Pak 1986). Among those with fasting hypercalciuria, secondary hyperparathyroidism indicative of true renal hypercalciuria was present in 0–100% of patients (a mean of 43%), whereas normal parathyroid function was encountered in 0–100% (a mean of 57%). In our 241 consecutive patients with stones evaluated in an outpatient setting (Pak et al 1980a), 23 presented with this picture, compared to 123 with absorptive hypercalciuria and 16 with renal hypercalciuria and secondary hyperparathyroidism.

In our experience, this ambiguous presentation is caused by incomplete exclusion of the effects of absorbed calcium in patients with absorptive or renal hypercalciuria. When calcium restriction is not maintained and the duration of fast is sufficient, there may be incomplete renal clearance of calcium absorbed from the intestinal tract. Under such circumstances, patients with absorptive hypercalciuria may present with fasting hypercalciuria and those with renal hypercalciuria may not show parathyroid stimulation (because of the suppressive effect of absorbed calcium). As previously mentioned, a prior treatment with sodium cellulose phosphate to remove the effects of absorbed calcium may disclose underlying absorptive hypercalciuria or renal hypercalciuria. In the former, sodium cellulose phosphate restores normal fasting urinary calcium without causing hyperparathyroidism, whereas in renal hypercalciuria the treatment may unmask parathyroid stimulation.

In some patients, however, fasting hypercalciuria with normal parathyroid function cannot be accounted for by an underlying absorptive or renal hypercalciuria. Typically, parathyroid function remains normal and fasting hypercalciuria persists despite an inhibition of calcium absorption by sodium cellulose phosphate. Fasting hypercalciuria with normal parathyroid function, exclusive of classic absorptive hypercalciuria or renal hypercalciuria, may be due to the following conditions (Fig. 10.3).

Renal phosphate leak (absorptive hypercalciuria type III)

In this condition, hypophosphataemia ensuing from renal phosphate leak has been implicated for the intestinal hyperabsorption of calcium by stimulating the renal synthesis of 1,25-$(OH)_2D$ (Shen et al 1977). This scheme is supported by findings of (a) low tubular threshold concentration of phosphate (Tm_P) and hypophosphataemia in patients with hypercalciuric nephrolithiasis without parathyroid stimulation, (b) ability of induced hypophosphataemia from limitation of intestinal phosphate absorption to stimulate the renal synthesis of 1,25-$(OH)_2D$ (Dominguez et al 1976), and (c) significant inverse correlation between serum 1,25-$(OH)_2D$ and serum phosphorus concentration (Gray et al 1977). Moreover, the presence of hypophosphataemia and/or high serum 1,25-$(OH)_2D$ provides an explanation (other than PTH excess) for the reported occurrence of fasting hypercalciuria, poor calcium conservation, reduced bone density and abnormal histomorphometric picture of bone (Bordier et al 1977) in hypercalciuric patients with normal parathyroid function.

Unfortunately, it has been difficult to show that a primary renal phosphate leak is present in a significant number of patients with hypercalciuric nephrolithiasis in the absence of parathyroid stimulation (Barilla et al 1979, Coe et al 1982). The occurrence of hypophosphataemia could not be confirmed in several reports. In our own study, serum phosphorus concentration was shown to depend on the study setting and dietary phosphate content (Barilla et al 1979). Serum phosphorus concentration was significantly lower in the outpatient setting with a high phosphate intake, with approximately 13% patients showing hypophosphataemia (< 2.5 mg/dl) (Pak et al 1980a). However, when these euparathyroid hypercalciuric patients were placed on a constant phosphate intake (800 mg/day) in an inpatient setting, serum phosphorus concentration significantly increased by approximately 0.71 mg/dl, leaving only 5.3% of patients with hypophosphataemia and low Tm_P. Serum phosphorus concentration and Tm_P were not significantly different between patients and control subjects during a comparable study setting.

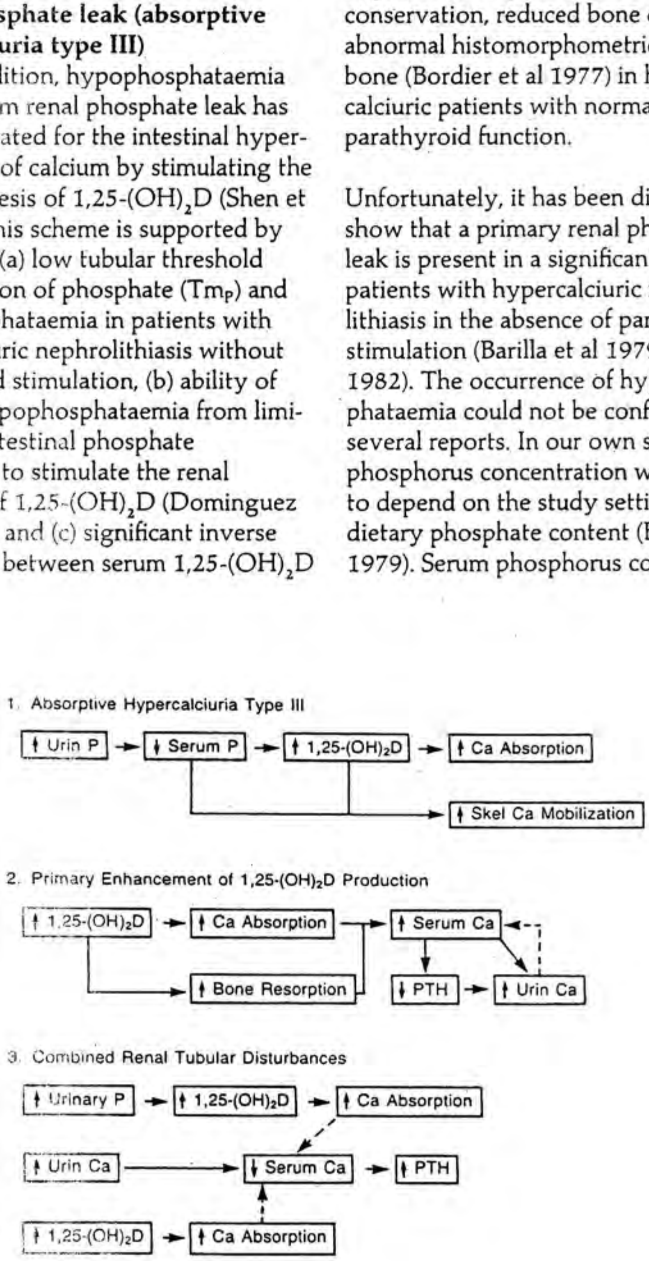

Fig. 10.3

Schemes for fasting hypercalciuria with normal parathyroid function. Dashed lines indicate compensatory inhibition.

The evidence that dietary phosphate deprivation stimulates the renal synthesis of 1,25-$(OH)_2D$ (Dominguez et al 1976) is an inadequate model for the phosphate leak hypothesis. There is no experimental model for absorptive hypercalciuria type III. The available data suggest that hypophosphataemia resulting from renal hyperphosphaturia does not stimulate the renal synthesis of 1,25-$(OH)_2D$. In familial hypophosphataemic rickets, serum 1,25-$(OH)_2D$ is not increased (Drezner et al 1980), although defective 1,25-$(OH)_2D$ may have originated independently.

In a recent study (Tieder et al 1985), several members of a kindred were reported with hypophosphataemia and low Tm_P, high serum 1,25-$(OH)_2D$ and calcium absorption, and hypercalciuria. They presented clinically with osteomalacia. Orthophosphate therapy resolved much of the biochemical picture of apparent hypophosphataemic absorptive hypercalciuria and brought clinical remission. Unfortunately, the ability of this treatment to restore normal intestinal calcium absorption was not tested. We were unable to show restoration of normal intestinal calcium absorption during orthophosphate therapy, despite reduction in serum 1,25-$(OH)_2D$.

Despite these reservations, hypophosphataemia due to renal phosphate leak is present in some patients with hypercalciuria and normal parathyroid function, albeit a small minority in our study (Barilla et al 1979). However, it is not clear that renal phosphate leak occurs primarily. In three such patients followed by us, primary hyperparathyroidism subsequently developed, with resolution of renal phosphate leak following successful parathyroidectomy. The result suggests that absorptive hypercalciuria type III may sometimes be mistaken for a subtle presentation of primary hyperparathyroidism.

Primary 1,25-$(OH)_2D$ production

Many of the biochemical characteristics of absorptive hypercalciuria can be explained by an overproduction of 1,25-$(OH)_2D$, whether it occurs independently (Insognia et al 1985, Broadus et al 1984b), or secondarily to the renal phosphate leak. These include intestinal hyperabsorption of calcium and parathyroid suppression. The parathyroid suppression can secondarily produce the high fasting urinary calcium sometimes encountered, because of the loss of PTH-dependent stimulation of the renal tubular reabsorption of calcium (Broadus et al 1984a). This conclusion is supported by the biochemical similarity of absorptive hypercalciuria to the state induced in normal subjects by exogenous 1,25-$(OH)_2D$ therapy (Broadus et al 1984a). Thus, the picture of fasting hypercalciuria with suppressed parathyroid function could occur from a primary increase in 1,25-$(OH)_2D$ synthesis, as a form of an acquired renal calcium leak.

Fasting hypercalciuria could also be due to the 1,25-$(OH)_2D$-dependent stimulation of bone resorption (Reynolds 1973). Exogenous 1,25-$(OH)_2D$ has been shown to augment urinary calcium excretion, even when patients are placed on a low calcium diet, as well as to increase urinary hydroxyproline (a marker of bone resorption) and serum osteocalcin (a marker of bone formation and turnover) (Zerwekh et al 1985).

The scheme for excessive 1,25-$(OH)_2D$ production is supported by the finding of high serum 1,25-$(OH)_2D$ in some patients with absorptive hypercalciuria (Broadus et al 1980) and the demonstration of accelerated in vivo 1,25-$(OH)_2D$ synthesis in patients with absorptive hypercalciuria selected from high extremes of serum 1,25-$(OH)_2D$ levels (Insognia et al 1985). This condition probably represents a variable fraction of those presenting with absorptive hypercalciuria, and should be distinguished from absorptive hypercalciuria type I and type II, in which a pathogenetic role of 1,25-$(OH)_2D$ is not implicated.

Combined renal tubular disturbances

(Fig. 10.3) (Pak 1985)

The occurrence of fasting hypercalciuria with normal parathyroid function could be explained by multiple disturbances in renal proximal tubular function, characterized by varying degrees of calcium leak, a disturbance in phosphate transport and accelerated 1,25-$(OH)_2D$ synthesis (Pak 1985, Coe et al 1982). This unifying scheme could explain the pathogenesis of both renal and absorptive hypercalciurias from the general defect originating in the kidney. The predominance of the renal calcium leak would lead to renal hypercalciuria with secondary hyperparathyroidism. On the other hand, the prominence of 1,25-$(OH)_2D$ synthesis, occurring independently or secondarily from renal phosphate leak, would produce a picture of absorptive hypercalciuria by enhancing intestinal calcium absorption and masking parathyroid stimulation. The occurrence of both renal calcium leak and renal phosphate leak or increased 1,25-$(OH)_2D$ synthesis may produce a picture of fasting hypercalciuria without parathyroid stimulation. Thus, renal hypercalciuria need not be accompanied by hyperparathyroidism, and absorptive hypercalciuria results secondarily from 1,25-$(OH)_2D$-dependent stimulation of intestinal calcium absorption.

Other

Another cause for the lack of manifestation of parathyroid stimulation in patients with renal hypercalciuria may be the relative impreciseness of the PTH assay used to assess parathyroid function. This conclusion is supported by the disclosure of parathyroid stimulation in the majority of patients with idiopathic hypercalciuria using one PTH assay (Coe et al 1973) but not at all employing another system by the same group of investigators in the same locality (Coe et al 1982). This discrepancy is not surprising in view of problems inherent in quantifying circulating PTH. Available radioimmunoassays for PTH vary with respect to sensitivity and to antigenic determinants recognized on the PTH molecule.

An altered set point for PTH release could explain the lack of parathyroid stimulation. The set point or 'calciumstat' for PTH release may be altered in certain disorders of parathyroid function (Habener & Potts 1978). In secondary hyperparathyroidism of chronic renal failure, the set point may be high. There may be an inverse relationship between serum PTH and serum calcium as in normal subjects. However, the concentration of serum calcium required to cause a 50% reduction in serum PTH may be much higher. There is also some suggestion that the converse occurs. That the set point for PTH release may be reduced is suggested by normal serum PTH (by amino-terminal assay) in the setting of low serum calcium in osteomalacic renal osteodystrophy (Frost et al 1981).

It has been suggested that an excessive production of prostaglandin E_2 might cause hypercalciuria. Treatment of hypercalciuric patients with nephrolithiasis with inhibitors of prostaglandin synthesis has been shown to reduce calcium excretion (Buck et al 1983).

PATHOPHYSIOLOGY OF HYPERURICOSURIA

Schemes for physiological derangements other than hypercalciuria are summarized in Table 10.5.

Uric acid is an end product of purine metabolism. It cannot be degraded in humans because of the absence of uricase, unlike the situation in lower mammalian species. A major site of disposal of uric acid is the kidney, where both secretion and reabsorption occur.

Hyperuricosuria may ensue when the serum concentration and the renal filtered load of uric acid are increased from (a) the provision of an excessive amount of substrate, e.g. a high dietary intake of purine-rich foods (Coe & Kavalach 1974) or an accelerated cellular degradation and release of nucleic acids, or (b) a disturbance in the enzymatic pathway for purine biosynthesis that causes overproduction of purine substrates for uric acid synthesis. A high urinary uric acid may occur transiently when renal tubular reabsorption of uric acid is impaired, e.g. during early stages of extracellular volume expansion and following administration of uricosuric agents such as probenecid. In the steady state, however, normal urinary uric acid is restored, because of the decline in serum concentration and renal filtered load of uric acid, even though the renal tubular reabsorption of uric acid remains impaired (Breslau & Pak 1983).

Hyperuricosuria may be the only recognizable physiological abnormality in patients with calcium nephrolithiasis. Such an abnormality (hyperuricosuric calcium nephrolithiasis) exists in approximately 10% of patients with renal calculi (Pak et al 1980a). Although hyperuricosuria may coexist with various forms of hypercalciuria previously enumerated, this section will consider only the pure disorder.

The most common cause for hyperuricosuria in patients with hyperuricosuric calcium nephrolithiasis is probably 'dietary overindulgence' with purine-rich foods (Coe & Kavalach 1974). Such individuals have a history of a liberal intake of meat, poultry and fish, and estimated purine intake is higher than in the control group. Hyperuricosuria may be produced by an oral purine load and ameliorated by dietary purine deprivation (Pak et al 1978, Coe & Boro 1974).

However, some patients with hyperuricosuric calcium nephrolithiasis (approximately 30%) have hyperuricosuria as a result of uric acid overproduction. Hyperuricosuria persists despite long-term purine deprivation. No further studies have been performed to elucidate the nature of this apparent urate overproduction.

Table 10.5 Schemes for physiological derangements other than hypercalciuria

Physiological derangement	Causes
Hyperuricosuria	Primary overproduction Dietary purine overindulgence or increased cellular degradation
Hyperoxaluria	High substrate availability (e.g. vitamin C or oxalate intake) Primary overproduction Intestinal hyperabsorption of oxalate (enteric hyperoxaluria)
Hypocitraturia	Renal tubular acidosis Enteric hyperoxaluria Hypokalaemia (e.g. thiazide therapy) High animal protein diet Urinary tract infection Other
Low urinary pH (uric acid stones)	Gout and chronic diarrhoeal syndrome High animal protein diet
Cystinuria	Impaired renal tubular reabsorption of cystine
High urinary pH and ammonium (struvite stones)	Infection with urea-splitting organisms

PATHOPHYSIOLOGY OF HYPEROXALURIA

Oxalate is derived both from in vivo synthesis and from intestinal abrorption. Once synthesized or absorbed, it is not further degraded in vivo. Its principal route of excretion is the kidney. Data on renal handling of oxalate are limited and conflicting. Of the 30 mg of oxalate that is excreted normally, 80–90% may be accounted for by in vivo synthesis and the remainder is derived from the diet.

Hyperoxaluria resulting from a primary derangement in renal handling of oxalate has not been recognized. Rather, the abnormality typically results from the increased serum concentrations and renal filtered loads due to (a) high substrate availability, e.g. administration of methoxyflurane or ascorbic acid, (b) enzymatic disturbance(s) in the oxalate biosynthetic pathway, as in primary hyperoxaluria (rare), or (c) increased intestinal absorption of oxalate.

Increased intestinal absorption of oxalate is the cause of hyperoxaluria in ileal disease (Earnest et al 1975). Two factors probably act in concert to cause intestinal hyperabsorption of oxalate:

1. Intestinal transport of oxalate may be primarily increased because of the action of bile salts and fatty acids on the permeability of intestinal mucosa to oxalate.
2. The total amount of oxalate absorbed may also be increased because of an enlarged intraluminal pool of oxalate available for absorption. The intestinal fat malabsorption characteristic of ileal disease may exaggerate soap formation with divalent cations, limit the amount of 'free' divalent cations to complex oxalate, and thereby raise the available oxalate pool.

In addition to the disturbance in oxalate metabolism, the intestinal absorption and renal excretion of calcium are often decreased in enteric hyperoxaluria, probably a reflection of the loss of the intestinal site of calcium absorption from disease or resection, of intraluminal binding of calcium by non-absorbed fatty acids, or of vitamin D deficiency associated with fat malabsorption. Urine output may be substantially reduced consequent to fluid loss from the intestinal tract. Urinary citrate may be low because of hypokalaemia and metabolic acidosis (Nicar et al 1983, Rudman et al 1982). Low urinary magnesium may result from impaired intestinal magnesium absorption.

The cause of the formation of calcium oxalate stones is multifactorial and includes hyperoxaluria as well as some of the other disturbances enumerated. Saturation of urine with respect to calcium oxalate may be increased because of high oxalate concentration and low urinary citrate and magnesium (which reduces complexation of calcium and oxalate), even though urinary calcium may be low. Low urine volume exaggerates urinary supersaturation. Moreover, inhibitor activity against crystallization of calcium salts is reduced because of low renal excretion of citrate.

PATHOPHYSIOLOGY OF HYPOCITRATURIA

Urinary citrate excretion is a function of filtration, reabsorption, peritubular transport and synthesis by the renal tubular cell (Baruch et al 1975). Approximately 80–90% of filtered citrate is normally reabsorbed. Citrate secretion is negligible in humans.

Although the exact physiology of renal handling of citrate has not been elucidated, several factors influence its excretion. Citrate excretion may be enhanced by alkalosis (Simpson 1967), PTH (Smith et al 1979), vitamin D, growth hormone and oestrogen. On the other hand, citrate excretion may be impaired by acidosis (Morissey et al 1963), hypokalaemia (Nicar et al 1984), androgen and urinary tract infection (probably from bacterial enzymatic degradation of citrate). Among these factors, acid-base status probably plays the most important role in the renal handling of citrate. For example, acidosis reduces urinary citrate by both enhancing renal tubular reabsorption and tissue citrate utilization. This mechanism accounts for the occurrence of hypocitraturia in renal tubular acidosis (complete or incomplete distal) (Preminger et al 1985b), chronic diarrhoeal states (including enteric hyperoxaluria) (Pak et al 1985a), hypokalaemia (from intracellular acidosis), thiazide therapy (from hypokalaemia) (Nicar et al 1984), and high animal protein diet (from elevated acid-ash content). The urinary citrate may also be low following strenuous physical exercise (from acquired acidosis), and high sodium intake (probably from sodium-induced potassium loss).

Hypocitraturia occurs with other causes of nephrolithiasis in approximately 50% of patients, and exists as a sole abnormality in 5% (Nicar et al 1983).

Distal acidification defect (type I) is the only form of renal tubular acidosis that is associated with nephrolithiasis. The stone formation is the result of high urinary pH and calcium and low urinary citrate. Calcium phosphate crystallization is promoted because of increased urinary saturation (from increased dissociation of phosphate and hypercalciuria) and reduced inhibitor activity (from hypocitraturia). The crystallization of calcium oxalate may be enhanced as well owing to increased saturation (from hypercalciuria and reduced citrate complexation of calcium) and impaired inhibitor activity (from hypocitraturia). Thus, the predominant stone constituent is calcium phosphate (hydroxyapatite). Calcium oxalate is also present in the stones typically, albeit as a minor constituent. Nephrocalcinosis may be often found with nephrolithiasis.

There is no evidence that nephrolithiasis is associated with proximal renal tubular acidosis (type II), or with hyporeninaemic hypoaldosteronism (type IV). Urinary citrate may be low because of acidosis. However, urinary calcium is often low due to bicarbonaturia in type II and renal insufficiency in type IV. Moreover, urinary pH is normal in type IV.

Distal renal tubular acidosis should not be confused with calcium oxalate nephrolithiasis of chronic diarrhoeal syndrome. In the latter case, metabolic acidosis is secondary to intestinal alkali loss from frequent diarrhoea. Stone (calcium) formation is consequent to low urinary citrate and volume. Underlying gastrointestinal disorders producing this syndrome include postgastrectomy state, inflammatory disease of the small bowel, bowel resection or bypass, and colitis. In states of malabsorption of fat, hyperoxaluria and low urinary magnesium may be present as well, contributing to calcium oxalate stone formation. Uric acid lithiasis may develop, though rarely, due to low urinary pH.

PATHOPHYSIOLOGY OF NON-CALCAREOUS STONES

Critical determinants for uric acid lithiasis are urinary pH lower than the dissociation constant for uric acid (5.5) and/or hyperuricosuria. Uric acid lithiasis often occurs in gouty diathesis.

We have previously utilized the term gouty diathesis (Pak et al 1986) to describe the overall clinical entity of uric acid lithiasis associated with primary gout (clinically manifest or latent). The invariant feature was the persistent passage of unusually acid urine (pH < 5.5) in which uric acid is sparingly soluble. Some patients had gouty arthritis or hyperuricaemia. Stone analysis disclosed uric acid alone, or in combination with calcium oxalate and/or calcium phosphate.

In some patients, we have found the above features of gouty diathesis except for the lack of uric acid on stone analysis. The stone analysis has disclosed only the presence of calcium oxalate and/or calcium phosphate. No obvious cause has been detected for the unusually low urinary pH, such as excessive intestinal alkali loss or a consumption of an animal protein-rich diet. It was presumed that urate-induced crystallization of calcium salts accounted for calcium nephrolithiasis (Pak et al 1979). Thus, gouty diathesis is the cause of both uric acid and calcium stones.

Uric acid lithiasis may also be found in secondary causes of purine overproduction, such as myeloproliferative states, glycogen storage disease, and malignancy. Chronic diarrhoeal syndromes (ulcerative colitis, regional enteritis, jejunoileal bypass surgery) may cause uric acid lithiasis by inducing net alkali deficit and lowering urine volume (thereby reducing urinary pH and augmenting urinary concentration of uric acid, respectively).

Cystine stones typically occur in approximately 10 000 persons in the United States who are homozygous for cystinuria (Thier & Segal 1972). These persons excrete abnormal amounts of cystine in urine of over 250 mg/g creatinine, as well as excessive amounts of other dibasic amino acids (lysine, arginine, ornithine), due to impaired renal tubular reabsorption of these amino acids. In addition, they show varying intestinal transport defects for these same amino acids. The stone formation is the result of poor aqueous solubility of cystine (Dent & Senior 1955, Pak & Fuller 1983).

Infection of the urinary tract with urea-splitting organisms may be associated with renal stones of struvite and of calcium carbonate apatite (Griffith & Musher 1973). The critical determinant is the formation of ammonia in urine owing to enzymatic degradation of urea by bacterial urease. The ammonia undergoes hydration to form ammonium and hydroxyl ions. The resulting alkalinity of urine augments dissociation of phosphate to form triphosphate ions and reduces the solubility of struvite. Thus, the urinary environment becomes supersaturated with respect to struvite. Although struvite stones may form de novo from infection alone, they also occur as a complication of other causes of renal calculi, such as hypercalciuria.

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Chapter 11

Medical diagnosis of nephrolithiasis

C Y C Pak

Introduction

Various physiological disturbances identified in nephrolithiasis are presumed to be important pathogenetically in the formation of kidney stones, as discussed in the previous chapter. Renal stones may be classified on the basis of these physiological derangements. This diagnostic classification has a practical value, since it permits the construction of a logical, physiologically meaningful therapeutic programme, to be discussed in the next chapter.

CLASSIFICATION OF NEPHROLITHIASIS

Historical perspective

There has been dramatic progress in the diagnostic separation of nephrolithiasis. This progress has been paralleled by advances in analytical methodology. Our own experience clearly illustrates this progress.

In 1972, we considered calcium nephrolithiasis to be comprised of three entities—idiopathic hypercalciuria, primary hyperparathyroidism, and normocalciuric nephrolithiasis (Pak et al 1972). The cause for stone formation was not disclosed in the last category, comprising 42.9% of patients.

In 1973, we introduced an inpatient protocol designed particularly for the elucidation of the pathophysiology of hypercalciuria associated with nephrolithiasis (Pak et al 1974). It entailed maintenance on a constant liquid synthetic diet for 3 days for better definition of hypercalciuria, assessment of parathyroid function from serum PTH and urinary cyclic AMP, and measurement of intestinal calcium absorption from faecal recovery of orally administered radiocalcium. Using this protocol, we reported in 1974 that hypercalciuria could be categorized into three forms—absorptive, renal and resorptive (Pak et al 1974).

The introduction of the test of fast and calcium load in 1975, designed for the simple diagnostic differentiation of hypercalciurias, paved the way for evaluation in an outpatient setting in lieu of costly inpatient hospitalization (Pak et al 1975). Our outpatient protocol, formalized in 1976, entailed collection of two 24-hour random urine samples and one following a diet restricted in calcium and sodium, and performance of fast and calcium load test. The inclusion of uric acid and oxalate as routine assays in urine permitted identification of hyperuricosuric calcium oxalate nephrolithiasis and enteric hyperoxaluria.

Using this protocol, we reported in 1980 that 89.2% of patients present with 'metabolic' disturbance(s), since they could be classified into one of the following categories: absorptive hypercalciuria, renal hypercalciuria, primary hyperparathyroidism, hyperuricosuric calcium nephrolithiasis, enteric hyperoxaluria, uric acid lithiasis, infection lithiasis, renal tubular acidosis and unclassified hypercalciuria (Pak et al 1980a). The omission of cystinuria was not an oversight, but probably reflected absence of referral from practising physicians because of our professed lack of expertise in the condition. The denotation of the term 'metabolic' to the classification was probably inappropriate, since environmental influences could have caused or contributed to the physiological disturbances disclosed.

Thus, 10.8% of patients were believed to have 'no metabolic abnormality' in our initial report. Since then, our diagnostic protocol has been refined by the routine inclusion of urinary citrate analysis in 1980. Among patients previously categorized as suffering from no metabolic abnormality, 48% had hypocitraturia (Nicar et al 1983). Moreover, some patients presented with a picture resembling gouty diathesis, with a persistent passage of unusually acid urine and uric acid or calcium oxalate nephrolithiasis, sometimes accompanied by hyperuricaemia and gout (Pak 1987, Pak et al 1986). Hypomagnesiuria was encountered in some patients with calcium nephrolithiasis. In the remaining patients, comprising approximately 3% of all patients, no disturbance was found.

Classification

It is therefore possible to identify a metabolic or physiological environmental cause of stones in more than 95% of patients. Various diagnostic categories and their relative frequency are shown in Table 11.1 (Pak 1988).

Table 11.1 Classification of nephrolithiasis

Absorptive hypercalciuria type I and type II	20–40
Renal hypercalciuria	5–8
Resorptive hypercalciuria (primary hyperparathyroidism)	3–5
Fasting hypercalciuria with normal PTH	15–25
Hyperuricosuric calcium nephrolithiasis	10–40
Hyperoxaluric calcium nephrolithiasis	2–15
Hypocitraturic calcium nephrolithiasis	10–50
Hypomagnesiuric calcium nephrolithiasis	5–10
Gouty diathesis	15–30
Cystinuria	< 1
Infection stones	1–5
Low urine volume	10–50
No disturbance and miscellaneous	< 3

After Pak 1988.

EVALUATION OF 'SINGLE STONE-FORMERS'

There is considerable debate regarding the extent of diagnostic evaluation which should be applied to patients presenting with a single stone episode. The following arguments have been engendered against an extensive diagnostic evaluation.

Patients who have formed one stone may not form another. Even if they should have recurrence, it may be 3–4 years before that occurs. Moreover, most single stone-formers have been reported to respond favourably to a conservative programme of high fluid intake and avoidance of dietary excesses (Hosking et al 1983). Thus, for an average patient with single stone formation, an extensive work-up would not seem to be indicated.

On the other hand, many patients with single episodes have various metabolic and environmental disturbances, placing them at increased risk for recurrent stone formation (Pak 1982). In some patients, the metabolic derangement disclosed may be a reflection of a multisystem disease (e.g. renal tubular acidosis, or renal hypercalciuria with secondary hyperparathyroidism). In such patients, medical treatments could be justified solely for the treatment of extrarenal manifestations (e.g. skeletal involvement of previously mentioned conditions). Finally, the cost of medical evaluation, even when it is extensive, is low relative to the cost of stone removal or of care for renal colic (Pak 1989). Thus, medical evaluation may be construed as cost-effective because of its potential for selection of an appropriate and effective prophylactic programme (Preminger et al 1985a).

The decision to investigate thoroughly a first-time stone former should ideally be shared by the physician and patient. Some patients may elect to seek a thorough evaluation.

Our own approach is to gauge the extent of evaluation according to the estimated potential or risk of new stone formation. Patients at risk might be middle age, white men with a family history of stones, those with intestinal disease (chronic diarrhoeal states), pathological skeletal fractures, osteoporosis, urinary tract infection, or gout. In these patients, we would recommend an extensive evaluation (to be described).

In single stone-formers without risk, the following abbreviated protocol might be applied (Table 11.2). A careful history should be taken for predisposing conditions, medications, dietary aberrations and for insufficient fluid intake (see Extensive evaluation for details). A multichannel blood screen should be performed in order to identify primary hyperparathyroidism (from high serum calcium), renal phosphate leak (from hypophosphataemia), distal renal tubular acidosis (from abnormal serum electrolytes) and gouty diathesis (from hyperuricaemia). Fresh spot urine sample should be cultured for urea-splitting organisms (suggestive of infection stones) and examined for pH (with a pH electrode) and crystalluria.

High pH (> 7.5) is compatible with infection lithiasis and low pH (< 5.5) with uric acid lithiasis. Identification of particular crystal type in the urinary sediment is compatible with, but is not diagnostic of, that type of nephrolithiasis. A qualitative examination of a spot urine sample for cystine (nitroprusside test) provides a clue to the presence of cystinuria. Abdominal roentgenological examination, with oblique views when necessary, is recommended. Radiopacity suggests stones of calcium oxalate and calcium phosphate. Cystine stones are also radiopaque, but tend to be more homogeneous with smooth edges.

Table 11.2 Evaluation of single-stone formers without risk

- History
  - Underlying predisposing conditions
  - Medications (Ca, vit C, vit D, acetazolamide, steroids)
  - Dietary excesses, inadequate fluid intake or excessive fluid loss
- Multichannel blood screen
  - High calcium: suggestive of primary hyperparathyroidism
  - Low phosphorus: renal phosphate leak
  - Low K and CO_2, high Cl: distal renal tubular acidosis
  - High uric acid: gouty diathesis
- Urine culture
  - Urea-splitting organisms: suggestive of infection lithiasis
- Urinary pH
  - > 7.5: compatible with infection lithiasis
  - < 5.5: uric acid lithiasis
- Urinary sediment for crystalluria
- Qualitative cystine
- X-ray
  - Radiopaque stones: calcium oxalate, calcium phosphate, magnesium ammonium phosphate (struvite), cystine
  - Radiolucent stones: uric acid, xanthine, 2,8-dihydroxyadenine, triamterene
- Stone analysis

Uric acid stones (as well as rare stones of xanthine, 2,8-dihydroxyadenine—Simmonds et al 1976—and triamterene) are radiolucent. An intravenous pyelogram would be useful in detecting radiolucent stones and in disclosing structural abnormalities of the urinary tract. The X-ray examination is also useful in the identification of nephrocalcinosis, medullary sponge disease and staghorn calculi.

Available stones should be analysed for crystalline composition. Identification of certain types of crystalline material is diagnostic of particular underlying conditions: uric acid for uric acid lithiasis; struvite, carbonate apatite and tricalcium phosphate for infection lithiasis; and cystine for cystinuria. The predominance of hydroxyapatite is suggestive, but not diagnostic, of stones of primary hyperparathyroidism and renal tubular acidosis. The finding of pure calcium oxalate or mixed calcium oxalate and hydroxyapatite is less useful diagnostically, since it could occur in several entities, including absorptive and renal hypercalciurias, hyperuricosuric calcium nephrolithiasis, enteric hyperoxaluria, hypocitraturic calcium nephrolithiasis, gouty diathesis and low urine volume.

The management of single-stone formers will be discussed in the next chapter.

EXTENSIVE DIAGNOSTIC EVALUTION

A more extensive evaluation, directed at the identification of underlying physiological derangements, should be performed in patients with recurrent nephrolithiasis as well as in single stone-formers at increased risk for further stone formation.

Several reliable protocols are available for the differentiation of different forms of nephrolithiasis. Our 'gold standard' has been the previously mentioned outpatient protocol (Pak et al 1980a). Introduced in 1976, it has undergone further refinement and has now been applied in more than 1500 patients.

Description of ambulatory protocol

This ambulatory evaluation requires three outpatient visits and may be completed within a month. It depends largely on procedures that should be available in a routine clinical laboratory. Certain specialized procedures may be obtained commercially. Such a work-up is cost effective, since it can be conducted at a fraction of the cost incurred during a hospitalization for renal colic. While there are other protocols with varying degrees of completeness, our protocol will be described in detail in order to illustrate the simplicity and reliability of this diagnostic evaluation (Table 11.3).

Any medication that could affect the metabolism of calcium, uric acid or oxalate should be discontinued before and during the period of evaluation whenever possible. These medications would include vitamin C, acetazolamide, calcium supplements, antacids, as well as those that may have constituted the stone treatment programme, such as thiazide, phosphate, allopurinol or magnesium.

Briefly, three 24-hour urine samples are collected. Two (random samples) are obtained while patients adhere to their customary diet and fluid intake. The third (restricted) sample is collected on the final day of a 7-day restricted diet (400 mg Ca, 100 mEq sodium/day and avoidance of oxalate-rich foods such as nuts, brewed tea, chocolate and dark greens). The purpose of obtaining the restricted sample is to standardize dietary factors so that hypercalciuria could be better defined. Moreover, the comparison of urinary values during a random situation from those of restriction permits an assessment of the role of environmental urinary risk factors.

The week on the restricted diet also provides essential preparation for the 'fast and calcium load test' (Pak et al 1975) that is performed on the third visit (to be described below).

Table 11.3 Outline of ambulatory protocol

	Blood			*Urine*								
	Complete blood count	SMA	PTH	pH	Total volume	Calcium	Uric acid	Creatinine	Sodium	Oxalate	Citrate	Qualitative cystine
Visit 1*	X	X		X	X	X	X	X	X	X	X	X
Visit 2**				X	X	X	X	X	X			
Visit 3***		X	X	X	X	X	X	X	X	X	X	
Fast						X		X				
Load						X		X				

* History and physical examination, radiological evaluation, 24-hour urine on random diet.
** 24-Hour urine on random diet, diet history and dietary instruction.
*** 24-Hour urine on restricted diet (400 mg calcium and 100 mEq sodium/day), fast and load test.

On the first visit, a thorough history is taken designed to elicit information regarding the nature and severity of stone disease and potential risk factors, according to an established format (Table 11.4). It includes total number of stones passed and surgically removed, stone composition if known and evidence of any existing stones. A careful estimate is made of frequency of stone episodes during the preceding 3 years in order to assess recent 'stone activity'. Specific dates and dosage of past treatment programmes for the control of stone disease are obtained. Personal history is sought for predisposing medical conditions, such as gout, intestinal disease and kidney infection. Family history is obtained for nephrolithiasis, gout and bowel disease. A list is compiled for all medications taken (currently and during the period covering stone disease), including vitamins and nutritional supplements. A careful diet history is obtained, directing particular attention to estimated fluid intake and intake of foods rich in sodium, calcium, oxalate and purines.

A KUB and/or intravenous pyelogram should be obtained if not performed previously. Stones passed or removed should be submitted for analysis. Blood (venous) tests obtained on the first visit include complete blood count and multichannel screen (calcium, phosphorus, creatinine, uric acid, sodium, potassium, chloride and carbon dioxide) (Table 11.4). The 24-hour random urine sample is analysed for calcium, uric acid, creatinine, sodium, oxalate, citrate, pH, total volume and qualitative cystine.

Table 11.4 Stone history

STONE DATA Time loss: Inpt Emerg Outpt Work missed
Dates: 1st stone: 2nd stone: 3rd stone:
Surgery type & dates: 1st: 2nd: 3rd: 4th:
# Stone in past 3 years Total no. No. spont. passed:
Episodes of colic requiring medications without stone passage last 3 years:
RADIOLOGY: Existing: (L) (R) Stone analysis:
Structural abnormals: (L) (R) Bladder
PAST THERAPY (Give dates)
Phosphates: Thiazides: Allopurinol:
Dates: (start) (stop) (start) (stop) (start) (stop)
Magnesium: Other:
Dates: (start) (stop) (start) (stop)
MEDICAL HISTORY (give dates)
Gout: Intestinal disease: UTIs:
Hypertension: Ulcers: Fracture: Diabetes:
Other:
FAMILY HISTORY (give relation)
Gout: Intestinal disease: PHPT: Hypertension:
Ulcers: Endocrine: Diabetes: Bone disease:
Stones:
MEDICATIONS TAKEN: (list medication & why taken)
1. 2. 3.
DO YOU USE? (list type & dose)
Antacids: Vitamins:
Calcium: Protein supp:
DO YOU PARTICIPATE IN? (list frequency & duration)
Jogging: Walking: Weightlifting: Golf:
Bicycling: Tennis: Other:
DO YOU HAVE ALLERGIES to food or medications Yes No
If yes, list:
DIETARY HABITS
Water: Tea: Coffee: Soda: Milk: Fruits:
ETOH: Salt: (L) (M) (H) Choc.: Nuts: Meat intake:
Cheese: Ice cream: Yogurt: Greens: Mex. Food:
PE: BP Pulse Resp. HT WT

Name: Age: Sex: Race: Occupation:

Table 11.5 This diet limits calcium and sodium. Certain foods that have large amounts of oxalate are also limited

	Foods allowed	Foods not allowed
Beverages	Carbonated drinks, coffee, lemonade, limeade, decaffeinated coffee, instant tea	*All milk* including canned milk, eggnog, milkshakes, malted milk, powdered milk and buttermilk, hot chocolate, cocoa mixes, brewed tea
Bread & cereals	Biscuits, bread, buns (hamburger), cornbread, muffins, pancakes, sweet rolls, flour tortillas, waffles, cooked and dry cereals	Salt topped bread, crackers and rolls, corn tortillas
Cheese	NONE	*All cheese* including cheddar cheese, cheese crackers, cheese foods, cheese puffs, cheese sauces, cheese sticks, cheese spreads, cottage cheese, cream cheese, dips, gouda, Parmesan cheese, processed cheese, provaloni, romano and Swiss cheese
Desserts & sweets	Honey, jelly, jam, marmalade, preserves, syrup, sugar, fruit cobblers and fruit pies, gelatin desserts, white and yellow cake with sugar icing, shortcake, bread pudding (no milk), tapioca, lemon sauce made with cornstarch, cookies, vanilla wafers, graham crackers, fruit ices and popsicles	Molasses, chiffon pie and cream pie,*all chocolate* in cakes, icings, pies and cookies, chocolate chips and chocolate syrup, pudding, custard, Boston cream pie, rice pudding,yogurt, *all ice cream*, mellorine, frozen custard, ice milk, sherbet and 'dietetic' ice cream
Fats	Butter, margarine, vegetable oil and most salad dressings, powdered or liquid non-dairy creamer; non-dairy whipped topping	Salad dressings made with cheese or sour cream, cream, ½ & ½ cream
Fruits & juices	Fresh, canned and frozen fruit, fresh, canned and frozen fruit juice	Dried fruits, tomato juice and vegetable juice cocktail, powdered fruit juice substitutes, rhubarb
Meats & meat substitutes	Eggs *Two average portions per day* of baked, boiled, broiled or fried beef, chicken, fresh water fish, fresh pork, seafood, tuna, turkey, veal or venison, homemade chili, meat pies and stews	Barbequed, cured, salty or smoked meat and fish, bacon, anchovies, canned meat and stews, canned salmon, caviar, canned chili, corned beef, corned beef hash, dried chipped beef, frankfurters, ham, herring, luncheon meats, frozen meat pies, pizza, salt pork, sardines, sausage, TV dinners (unlesss low sodium content indicated)
Starches	Corn, macaroni, noodles, potatoes, rice, and spaghetti, dried beans and dried peas in moderation	Macaroni and cheese, potato chips, corn chips, tortilla chips, corn pudding
Vegetables & soups	Fresh, canned and frozen vegetables, homemade soups	Sauerkraut and other vegetables prepared in brine, canned pork & beans, hominy, *all 'greens'* such as turnip greens, spinach, collard greens, mustard greens, beet greens and polk, cheese soups, canned broth, bouillon cubes, canned soup (unless low sodium content indicated)
Miscellaneous	Spices, herbs and extracts, unsalted peanut butter, *small amounts* of meat tenderizer, brown gravy and sauces such as ketchup, chili sauce, spaghetti sauce, steak sauce and Worcestershire sauce because these *do contain salt!*	*Added salt*, seasoned salt, monosodium glutamate (MSG), prepared horseradish and mustard, olives, pickles, salted nuts, salted popcorn, regular peanut butter, soysauce, cream gravies and white sauce, hollandaise, newburg sauce
Supplements	*None*	Vitamins plus minerals and *vitamin C*
Medications	As directed by physician	

Instructions for limiting salt:

1. Use no salt or seasoned salt at the table.
2. Eat foods only lightly salted during preparation.
3. Do not add salt in the preparation of foods to which salt is added in processing, e.g. canned vegetables.
4. When preparing food from a recipe, use half the amount of salt specified.

On the second visit, another 24-hour urine sample collected on a random diet and fluid intake is analysed for calcium, uric acid, creatinine, sodium, pH and total volume. The patient is then instructed on a diet restricted in calcium (400 mg/day), sodium (100 mEq/day) and oxalate, to be maintained until the third visit (at least 7 days). This instruction may be given by a trained nurse or technician and not necessarily by a dietitian, using Table 11.5.

On the third visit, another 24-hour urine sample collected on the seventh day of the restricted diet is assayed for calcium, uric acid, creatinine, sodium, oxalate, citrate, pH and total volume (Table 11.4). A fasting venous blood sample is analysed for multichannel screen and immunoreactive parathyroid hormone (PTH). The patient undergoes 'fast and calcium load test' on the morning of the third visit (Pak et al 1975). Essential requirements of this test are:

1. Patients are kept on a low calcium, low sodium diet for at least one week and fasted for 10–12 hours in order to eliminate the contributions of absorbed calcium on fasting calcium excretion.
2. Ample fluid intake (as distilled water) is provided in order to assure adequate hydration.
3. A 1 g calcium load is given orally in a standard meal, the response to which has been well characterized in normal subjects.
4. Urine samples are collected as accurately as possible (with patients urged to empty the bladder as completely as possible) for 2 hours before and for 4 hours after 1 g calcium load (representing fasting and postload samples).

While the exact timing may vary to accommodate the special requirements of the laboratory or patients, the following schedule has been found to be suitable. Patients fast for 12 hours from 9 p.m. of the 7th day of the restricted dietary regimen. Distilled water (300 ml each) is provided at 9 p.m. and midnight. At 7 a.m. of the following day, patients completely empty their bladder (discarding urine) and then drink an additional 600 ml of distilled water (while fast is continued). Urine is collected from 7 a.m. to 9 a.m. (fasting sample). At 9 a.m., after collection of the fasting urine sample, 1 g of calcium (elemental) is mixed in a liquid synthetic meal (250 ml) and is given orally. A urine sample (postload) is collected from 9 a.m. to 1 p.m. over a 4-hour period. Fasting and postload samples are analysed for calcium and creatinine. The liquid synthetic diet may be substituted by other standard meals such as milk. If so, it is advised that normal control data be obtained separately, rather than relying on the control values obtained with the synthetic meal.

INTERPRETATION OF TESTS

Assessment of the effect of environmental influences

Results in urine samples obtained during a random diet, especially when compared to those in urine samples collected during a restricted diet, permit an assessment of environmental risk factors.

When urinary calcium in random samples exceeds that in restricted samples, one should suspect that the normal intake of calcium is excessive, or that the intake of other factors (such as sodium, carbohydrate or acid ash) is exaggerated. Under steady-state conditions in the absence of diarrhoea or excessive sweating, urinary sodium approximates the dietary intake by less than 20 mEq/day. Thus, the finding of urinary sodium exceeding 150 mEq/day suggests that sodium intake is high. In patients with normouricaemia without a history of gout, a high urinary uric acid excretion (> 700 mg/day) indicates a high purine intake. A history of preference for animal proteins supports this suspicion. In the absence of bowel disease, high urinary oxalate (> 44 mg/day) indicates that the consumption of oxalate-rich foods (spinach, nuts, chocolate, brewed tea) is high or that vitamin C supplements (substrate for oxalate synthesis) are taken. The finding of normal urinary oxalate during the restricted diet supports this conclusion. Low urinary volume suggests an inadequate fluid intake, excessive fluid loss or profuse sweating. In the absence of abnormal gastrointestinal fluid loss or sweating, urine volume is less than the total fluid intake by approximately 500–1000 ml/day.

Results during restricted diet and response to fast and calcium load

The measurement of urinary calcium on the restricted diet permits a definition of hypercalciuria. The finding of urinary calcium exceeding 200 mg/day is indicative of hypercalciuria, irrespective of age, and sex and body size (Pak et al 1974). The response to the fast and calcium load test allows differentiation of varying forms of hypercalciuria (Pak et al 1975). A high calcium excretion during the fasting state in the setting of normocalcaemia (and hence, normal renal filtered load of calcium) denotes that an impaired renal tubular reabsorption of calcium (renal calcium leak) is present. The co-occurrence of high serum PTH with fasting hypercalciuria supports the diagnosis of renal hypercalciuria with secondary hyperparathyroidism. It should be emphasized that the value of fasting urinary calcium depends on the preparation of patients on a limited calcium and sodium diet before the test. In patients with intestinal hyperabsorption of calcium, abnormally high values for fasting urinary calcium may be found if they are not prepared properly, due to the delayed clearance of absorbed calcium and persistent parathyroid suppression (and hence inhibited renal tubular reabsorption of calcium) (Pak & Galosy 1979). Fasting hypercalciuria following adequate preparation suggests occurrence of primary 1,25-$(OH)_2D$ excess, renal phosphate leak or combined disturbances in renal proximal tubular function (see Ch. 10). Fasting urinary calcium is best expressed as mg/dl glomerular filtrate (GF), since it is reflective of renal function rather than of muscle mass or body size (Pak et al 1980a). This measure may be obtained by simply multiplying urinary calcium in mg/mg creatinine by the corresponding serum creatinine in mg/dl.

The extent of renal calcium excretion after an oral load of calcium provides an indirect assessment of intestinal calcium absorption. In patients with normal fasting urinary calcium (< 0.11 mg/dl GF), urinary calcium postcalcium load of > 0.2 mg/mg creatinine indicates that intestinal calcium absorption is high and suggests the diagnosis of absorptive hypercalciuria. The urinary calcium postcalcium load is best expressed in mg/mg creatinine, since it is a function of a fixed oral calcium load (Pak et al 1980a).

DIAGNOSTIC CRITERIA

Diagnostic criteria for the major forms of nephrolithiasis, constructed from results of the ambulatory protocol, are presented in Table 11.6.

Absorptive hypercalciuria type I is characterized by normocalcaemia; normophosphataemia, normal fasting urinary calcium (< 0.11 mg/100 ml glomerular filtrate [GF]), exaggerated urinary calcium following an oral calcium load (> 0.2 mg/mg creatinine), normal or suppressed parathyroid function (normal serum immunoreactive PTH), and urinary calcium on a restricted diet (400 mg calcium and 100 mEq sodium/day) of more than 200 mg/day. These values reflect increased intestinal calcium absorption, resultant parathyroid suppression and hypercalciuria.

Table 11.6 Diagnostic criteria

	PHPT	AH-I	AH-II	RH	FH	HUCN	EH	Hypocit
Serum Ca	↑	N	N	N	N	N	N/↓	N
Serum P	↓/N	N	N	N	N	N	N/↓	N
Urinary Ca, 24-h	↑/N	↑	N	↑	↑	N	↓	N
Serum PTH	↑	N/↓	N/↓	↑	N	N	N/↑	N
α	↑/N	↑	↑/N	↑/N	↑	N	↓	N
Urinary Ca (1 g Ca load)	↑/N	↑	↑	↑/N	↑	N	↓	N
Urinary Ca (fasting)	↑/N	N	N	↑	↑	N	↓	N
Bone density	N/↓	N	N	N/↓	N/↓	N	N/↓	N
Urinary uric acid	N/↑	N/↑	N/↑	N/↑	N/↑	↑	↓	N
Urinary oxalate	N/↑	N/↑	N/↑	N/↑	N/↑	N	↑	N
Urinary citrate	N	N/↓	N/↓	N/↓	N/↓	N/↓	↓	↓

Fasting samples represent 2-hour collections obtained in morning following an overnight fast. 1 g Ca load samples were obtained over a 4-hour period subsequent to oral ingestion of 1 g Ca. Fractional Ca absorption (α) was obtained from faecal recovery of radioactivity following oral administration of radiocalcium with 100 mg Ca. Bone density was obtained in distal third of radius by photon absorptiometry. PTH = immunoreactive parathyroid hormone; ↑ = high; ↓ = low; N = normal; PHPT = primary hyperparathyroidism; AH-I = absorptive hypercalciuria type I; AH-II = absorptive hypercalciuria type II, RH = renal hypercalciuria; FH = fasting hypercalciuria with normal parathyroid function; HUCN = hyperuricosuric calcium nephrolithiasis (pure presentation); EH = enteric hyperoxaluria; Hypocit = hypocitraturic calcium nephrolithiasis (pure presentation).

Absorptive hypercalciuria type II is characterized by the same biochemical features as those of type I except for normocalciuria (< 200 mg/day) on a restricted diet (400 mg calcium and 100 mEq sodium/day). If these patients are placed on a diet of 1000 mg calcium and 100 mEq sodium/day, urinary calcium exceeds 4 mg/kg or 250 mg/day.

Renal hypercalciuria is manifested by normocalcaemia, high fasting urinary calcium (> 0.11 mg/100 ml GF), and enhanced parathyroid activity (high serum immunoreactive PTH). These results indicate a renal leak of calcium with compensatory parathyroid stimulation. Serum PTH must be elevated to confirm the diagnosis of renal hypercalciuria. Bone density may be low in patients with renal hypercalciuria and, in some, osteopenia may occur (Lawoyin et al 1979). Thiazide restores normal urinary calcium and serum PTH without causing hypercalcaemia.

Primary hyperparathyroidism may be recognized by the presence of hypercalcaemia, hypophosphataemia, hypercalciuria, and increased or inappropriately high serum PTH. Hypercalcaemic symptoms, peptic ulcer, or bone disease (osteitis, pathological fractures, osteoporosis) may be present.

Fasting hypercalciuria with normal parathyroid function depicts normocalcaemic hypercalciuric patients with calcium nephrolithiasis, in whom the diagnosis of absorptive or renal hypercalciurias cannot be made with certainty (Pak et al 1980a). It is represented by normocalcaemia, high fasting urinary calcium (> 0.11 mg/dl GF) and normal serum PTH. In many patients, this presentation is accountable by an incomplete clearance of absorbed calcium in patients with an underlying absorptive or renal hypercalciuria (see Ch. 10). A more complete elimination of the effect of absorbed calcium by prior treatment with sodium cellulose phosphate may provide further clarification (to be described). In patients with persistent fasting hypercalciuria and normal serum PTH (despite preparation with sodium cellulose phosphate), one should suspect renal phosphate leak (previously called absorptive hypercalciuria type III), primary 1,25-(OH)$_2$D excess, or combined disturbances in renal proximal tubular function (see Ch. 10). In renal phosphate leak, serum phosphorus and renal threshold concentration of phosphorus are less than 2.5 mg/dl and remain low despite examination in an inpatient setting and avoidance of dietary phosphate excess (Shen et al 1977, Barilla et al 1979).

Hyperuricosuric calcium nephrolithiasis (pure presentation) is characterized by hyperuricosuria (urinary uric acid > 600 mg/day on mean of three samples and on at least two of the three samples), normocalcaemia, normal fasting and calcium load response, normal urinary calcium and oxalate (< 44 mg/day), and calcium nephrolithiasis. Hyperuricosuria, defined functionally here by the upper normal limit of 600 mg/day, correlates with the urinary supersaturation with respect to monosodium urate and with the propensity for calcium stone formation (Pak et al 1977b). (Other laboratories employ a higher upper limit for urinary uric acid, e.g. 750 mg/day for women and 800 mg/day for men.) Urinary pH is typically greater than 5.5. Hyperuricosuria may be the only abnormality in patients with calcium stones, or it may coexist with various forms of hypercalciuria.

Hyperoxaluria, defined as urinary oxalate > 44 mg/day, is associated with calcium oxalate stones. If urinary oxalate is > 80 mg/day, primary or enteric hyperoxaluria is probably present. In primary hyperoxaluria, urinary glycolate or glycerate may be increased in addition to oxalate. Moreover, oxalosis (tissue deposition of calcium oxalate), anaemia, and renal failure are common in primary hyperoxaluria. In enteric hyperoxaluria, there is a history of small bowel disease, ileal bypass, or resection (Smith et al 1972). Urinary calcium is typically low (< 100 mg/day). Serum calcium and magnesium may be low or low-normal and parathyroid function may be stimulated. Serum bicarbonate and urinary citrate may be reduced. Even in the absence of intestinal disease, a mild-to-moderate hyperoxaluria (urinary oxalate 44–80 mg/day) may occur with vitamin D therapy, overindulgence in oxalate-rich foods (particularly spinach), or severe dietary calcium deprivation. Mild hyperoxaluria may also occur in patients with increased calcium absorption, such as those suffering from absorptive hypercalciuria.

Hypocitraturic calcium nephrolithiasis in the pure presentation refers to the condition in which hypocitraturia (urinary citrate < 320 mg/day) is present alone without other physiological derangements (such as hypercalciuria, hyperuricosuria) (Nicar et al 1983). Hypocitraturia often coexists with other abnormalities. It may be caused by distal renal tubular acidosis (Preminger 1985b), metabolic acidosis of chronic diarrhoeal states or thiazide-induced hypokalaemia (Nicar et al 1984). Complete distal renal tubular acidosis is characterized by hyperchloraemic metabolic acidosis (high serum chloride, low serum potassium and carbon dioxide) and high urinary pH (> 6.8) in the absence of infection of the urinary tract. There is also an incomplete form of renal tubular acidosis characterized by normal serum electrolytes, but an impaired ability to acidify the urine following ammonium chloride load. Both complete and incomplete forms may be associated with hypercalciuria, hypocitraturia, calcium nephrolithiasis and nephrocalcinosis. A typical stone analysis shows a preponderance of hydroxyapatite with calcium oxalate as a minor constituent.

Chronic diarrhoeal states capable of producing hypocitraturia and calcium nephrolithiasis include ileal disease or resection, gastrectomy, ulcerative colitis or colectomy. The degrees of hypocitraturia is generally proportional to the severity of intestinal fluid loss. In severe diarrhoeal states, urinary citrate may be very low (< 50 mg/day). Besides hypocitraturia, there may be serum electrolyte abnormalities of acquired metabolic acidosis (due to intestinal fluid loss) and low urinary pH. Some patients may show full features of enteric hyperoxaluria.

The invariant feature in gouty diathesis is the persistent passage of unusually acid urine (pH < 5.5) (Pak 1987, Pak et al 1986). The cause for low urinary pH cannot be readily ascertained. Some patients may give a positive personal or family history of gouty arthritis. Some patients may present with hyperuricaemia or hypertriglyceridaemia. Stones formed may be uric acid alone, calcium oxalate-phosphate alone, or a mixture of the two. Some patients may form uric acid on one occasion and calcium stones on another occasion. Uric acid stones are radiolucent.

Cystine stones are generally formed by patients with homozygous cystinuria. It is suspected if the cyanide-nitroprusside test of urine is positive. It is documented by quantitative test for cystine showing cystine excretion greater than 250 mg/g creatinine and by the identification of cystine on stone analysis. Cystine stones are radiopaque though to a lesser degree than calcium stones.

Lithiasis due to infection is disclosed by the presence of magnesium ammonium phosphate on stone analysis. Such struvite stones are often associated with pyuria, positive urine culture for urea-splitting organisms (*Proteus*, certain species of *Staphylococcus*, *Pseudomonas* and *Klebsiella*), and high urinary pH (> 7.5) (Griffith 1978). Struvite stones are radiopaque and sometimes may attain a large (staghorn) size; they usually occur as mixtures with calcium carbonate apatite and tricalcium phosphate or less commonly with calcium oxalate.

In some patients without any of the physiological derangements enumerated above presenting with calcium nephrolithiasis, urine volume may be low (< 1000 ml/day) due to a disdain for drinking fluids. The remaining patients without any metabolic or environmental disturbance comprise those with no disturbance. In this refined classification, the previous entity of no metabolic abnormality now includes hypocitraturic calcium oxalate nephrolithiasis occurring as a sole abnormality, gouty diathesis, low urine volume and no disturbance.

A SIMPLIFIED AMBULATORY EVALUATION

The previously described ambulatory protocol is worthy of consideration for the evaluation of patients with recurrent nephrolithiasis, or with high risk, because of its high diagnostic yield and reliability. Unfortunately, this protocol may be too cumbersome for ready adoption in the setting of some practising physicians. We have therefore devised a simplified approach to the evaluation of nephrolithiasis.

Initial screen for urinary risk factors for renal stone formation (stone risk profile)

Recent advances in analytical technology now allow reliable determination of various urinary constituents that could influence renal stone formation. These assays include calcium, oxalate and citrate (which could result from disturbed metabolism of these substances), as well as total volume and sodium (which are sequelae of environmental or dietary influences). From such determinations, it is possible to calculate urinary saturation with respect to stone-forming salts. Thus, a profile of stone-forming risks can now be constructed and depicted graphically for easy recognition (Pak et al 1985). This service is available commercially in the United States.

Urinary collection and determinations. A 24-hour urine sample was collected during a random diet and fluid-intake after a temporary withdrawal of any treatment imposed for the control of stone disease. Urinary determinations are done for calcium, oxalate, uric acid, citrate, pH, total volume, sodium, sulphate, phosphorus,magnesium, potassium and ammonium. From these determinations, activity products of calcium oxalate, brushite, monosodium urate and struvite are calculated using a computer programme. The concentration of undissociated uric acid is also computed by the same programme. These tests (except for potassium and ammonium) are separated into three categories.

*Metabolic factors.*Metabolic factors include calcium, oxalate, uric acid, citrate and pH. This categorization recognizes the important pathogenetic role in stone formation of hypercalciuria, hyperoxaluria, hyperuricosuria, hypocitraturia and abnormally high or low urinary pH (Pak 1983). Hypercalciuria would increase urinary saturation of calcium oxalate and calcium phosphate, whereas hyperoxaluria would raise that of calcium oxalate (Pak & Holt 1976). Hyperuricosuria would promote urate-induced crystallization of calcium oxalate (Pak et al 1979) and increase the amount of undissociated uric acid. Hypocitraturia may enhance urinary saturation of calcium salts by reducing citrate complexation of calcium (Pak et al 1982), as well as reduce inhibitor activity against crystallization of calcium salts (Nicar et al 1987). Abnormally low urinary pH (< 5.5) may be conducive to uric acid lithiasis because of reduced dissociation of uric acid and consequent elevated concentration of undissociated uric acid (Pak et al 1986). Abnormally high urinary pH (> 7) may accentuate calcium phosphate saturation (from increased dissociation of phosphate). These disturbances may be metabolic in origin, since they may result from various physiological derangements. Thus, hypercalciuria may arise from increased intestinal absorption, impaired renal tubular reabsorption or excessive skeletal mobilization of calcium (Pak et al 1974); hyperoxaluria from an enhanced intestinal absorption or endogenous synthesis of oxalate; hyperuricosuria from excessive urate synthesis; hypocitraturia from metabolic acidosis; low urinary pH in association with gouty diathesis and high urinary pH from renal tubular acidosis (distal). Dietary excesses could, of course, modify or contribute to these disturbances.

Environmental factors. Environmental factors include total volume, sodium, sulphate, phosphorus and magnesium.

Low urine output from an inadequate fluid intake would increase urinary concentration of stone-forming constituents and thereby raise the saturation of stone-forming salts (Pak et al 1980b). High urinary sodium from an excessive dietary 'salt' intake may increase urinary calcium, attenuate hypocalciuric action of thiazide and promote sodium urate-induced crystallization of calcium oxalate. High urinary sulphate suggests a high acid ash content of the diet, which may contribute to hypocitraturia. High urinary phosphorus provides a reflection of an exaggerated intake of dairy and meat products; it may raise urinary saturation of calcium phosphate. Low urinary magnesium from an inadequate intake may accentuate urinary saturation of calcium oxalate because of inadequate complexation of oxalate by magnesium.

Physicochemical factors. Physicochemical factors are represented by urinary saturations of calcium oxalate, brushite, monosodium urate, struvite and uric acid (Pak et al 1977a). Urinary saturations are estimated from activity products (for the first four salts) and from the concentration of undissociated uric acid. Supersaturation with respect to stone-forming salts is a critical requirement for stone formation.

Derivation of normal values. For each risk factor, the upper or lower normal limit was established. These limits approximate mean $+ 2$ SD (for calcium, oxalate, uric acid, pH, sodium, sulphate and phosphorus) or mean $- 2$ SD (for citrate, pH and magnesium) of values from normal subjects in our laboratory. For total volume, the low normal limit reflects the desired level.

For the derivation of upper normal limits for physicochemical factors, activity product of calcium oxalate, brushite, monosodium urate and struvite, and the concentration of undissociated uric acid were calculated from urine samples (24-h) obtained from normal subjects without stones.

For each urine sample, the results are expressed as relative supersaturation (RS), calculated as the ratio of activity product (or concentration of undissociated uric acid) in the particular urine sample and the corresponding *mean* activity product (or undissociated uric acid) from normal subjects. Thus, the upper normal limit for RS is 2 for calcium oxalate, brushite, monosodium urate and uric acid, and 75 for struvite.

Display of data. In order to provide a visual display of all available data in a single report, each risk factor is assigned a vertical line with linear or logarithmic scales. Risk factors are grouped into metabolic, environmental or physicochemical risks. A horizontal line intersecting each vertical scale at approximate midpoint represents upper or lower normal limit. The direction of increasing values is appropriately adjusted, such that values below the horizontal line represent normal values (reduced risk), and above the line abnormal values (increased risk). For example, values for urinary calcium increase upward whereas those for citrate increase downward on the scale. For metabolic and environmental risks, values above the horizontal dashed line indicate abnormally high or abnormally low determinations. For physicochemical risks, values above the horizontal dashed line represent relative supersaturation (greater degree of supersaturation than in normal subjects) with respect to specified stone-forming salt(s).

A sample display in a patient with recurrent calcium nephrolithiasis is shown in Figure 11.1.

Value and limitations of stone risk profile

The stone risk profile has an obvious diagnostic utility (Pak 1988). Urinary calcium exceeding 250 mg/day is indicative of the presence of one of the varying forms of hypercalciuria (Table 11.1). Urinary uric acid of greater than 600 mg/day is indicative of hyperuricosuria calcium nephrolithiasis, oxalate exceeding 44 mg/day hyperoxaluria, citrate less than 320 mg/day hypocitraturic calcium nephrolithiasis, pH < 5.5 gouty diathesis, pH > 7.5 infection stones, and volume < 1 litre/day low urine volume. The association of relative supersaturation of uric acid with low urinary pH further supports the diagnosis of gouty diathesis. A finding of relative supersaturation of struvite with high urinary pH is almost diagnostic of infection stones.

However, a definitive diagnosis of a particular underlying derangement generally cannot be made without further tests. In general, it is desirable to confirm the presence of hypocitraturia or hyperuricosuria on repeat measurements. Moreover, the stone risk does not permit differentiation of different forms of hypercalciuria.

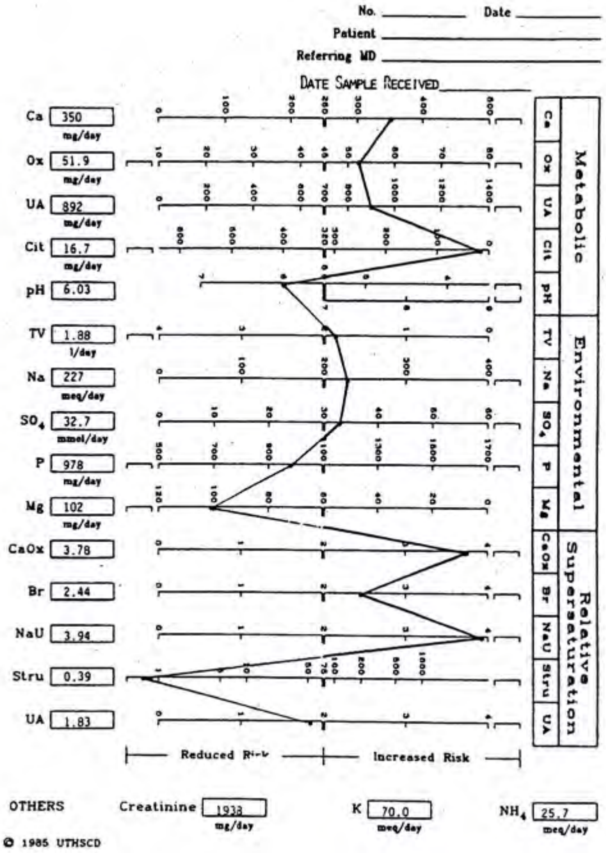

Fig. 11.1

Urinary stone risk profile in a patient with recurrent calcium nephrolithiasis.

Sodium cellulose phosphate (SCP) trial

If hypercalciuria is present on the random dietary regimen, the following studies may be performed to delineate the cause for the hypercalciuria:

1. Place on limited diet (Ca, Na, oxalate) for 1 week.
2. Obtain 24-hour urinary Ca on day 4 of above diet.
3. Take SCP 5 g tid with meals on days 5–7.
4. Obtain 24-hour urinary Ca on day 7.
5. Obtain fasting urinary Ca and Cr, serum Ca, P, creatinine and PTH on day 8.

The patient is instructed to adhere to a diet restricted in calcium (400 mg/day) and sodium (100 mEq/day) for one week in an outpatient setting, using the diet table previously described (Table 11.5). If urinary calcium on day 4 of this diet is less than 200 mg/day, the patient probably has absorptive hypercalciuria type II and no further studies would be necessary.

If urinary calcium exceeds 200 mg/day on the restricted diet, the patient takes sodium cellulose phosphate (15 g/day in divided doses with meals) in order to reduce intestinal calcium absorption. The hypocalciuric response to this treatment in normal subjects and in patients with absorptive hypercalciuria type I or type II has been defined (Fig. 11.2). A normal decrement in 24-hour urinary calcium suggests the diagnosis of absorptive hypercalciuria, especially if serum PTH is normal. A subnormal decrement in 24-hour urinary calcium associated with high serum PTH suggests renal hypercalciuria. A subnormal decline in urinary calcium with normal serum PTH is indicative of excessive skeletal mobilization of calcium (fasting hypercalciuria with normal parathyroid function).

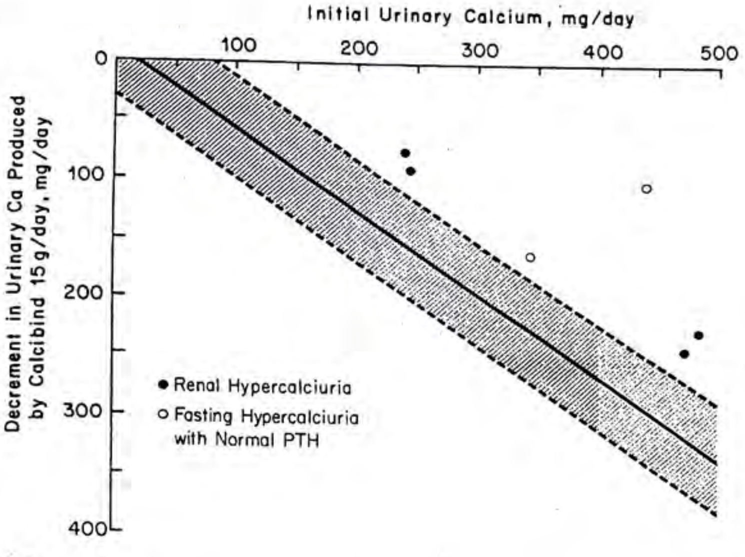

Fig. 11.2

Decrement in urinary calcium produced by sodium cellulose phosphate therapy (SCP) (15 g/day). Shaded area represents regression line and 95% confidence limits for values in normal subjects and in patients with absorptive hypercalciuria.

EVALUATION OF PATIENTS UNDERGOING PERCUTANEOUS NEPHROSTOLITHOTOMY OR EXTRACORPOREAL SHOCK WAVE LITHOTRIPSY

The objective of medical diagnostic evaluation in patients undergoing percutaneous nephrostolithotomy or extracorporeal shock wave lithotripsy is to offer selective medical treatment in an effort to prevent further stone formation, and to overcome any non-renal complications if present (see Ch. 12). It is assumed that removal of stones alone by innovative technology does not prevent future recurrence of stone-formation. We employ the same criteria previously described for selecting simplified or an extensive diagnostic evaluation, reserving an extensive work-up for patients with recurrent nephrolithiasis, or those at risk for further stone formation.

However, the exact timing for performing an extensive diagnostic evaluation depends on several factors, including presence of ureteral obstruction, acute renal functional deterioration or infection, and urgency for performing stone removal. It has been suggested that the renal excretion of certain stone risk factors (such as calcium) may be impaired in the presence of ureteral obstruction and may remain disturbed for several weeks following relief of obstruction. Although no definitive studies are available, a similar disturbance might be expected for endourologic surgery, shock wave lithotripsy or acute urinary tract infection. Thus, it would seem advisable to postpone an extensive 'metabolic' evaluation (like the extensive ambulatory protocol previously described; until at least 1 month after removal of stones, relief of obstruction, or treatment of infection. In patients without obstruction or acute infection in whom procedure for stone removal could be postponed, an extensive evaluation may be performed before percutaneous nephrostolithotomy or shock wave lithotripsy.

The following is our suggested guideline for diagnostic evaluation. First, assess severity of stone disease (single or recurrent), search for obstruction, renal functional deterioration and infection, and evaluate the urgency for stone removal.

Second, consider that an extensive diagnostic evaluation be conducted before stone removal in patients without obstruction or infection, in whom procedure for stone removal could be postponed.

Third, in remaining patients, conduct a simplified diagnostic programme as described for single stone-formers (Table 11.2).

Fourth, in those with recurrent nephrolithiasis, or those at risk for further stone formation, postpone an extensive diagnostic evaluation until at least 1 month after the stone removal or treatment of infection. Our extensive ambulatory protocol or its variant would be preferable (Table 11.3). If patients live far away and cannot meet the requirements of the ambulatory protocol, a simplified version with a submission of a 24-hour urine for stone risk profile might be a reasonable alternative. Sodium cellulose phosphate trial may be performed if hypercalciuria is present.

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Chapter 12

Medical management of nephrolithiasis

C Y C Pak

Introduction

The main objective of medical therapy of nephrolithiasis is to prevent the recurrent formation of stones in patients who are at risk of further stone development. There is no medical treatment that is known to provide a complete cure of the disease. Available medical treatments represent conservative measures (such as changes in diet or fluid intake) and medications which are directed at restoring normal urinary biochemistry and physicochemistry. There is no evidence that a short-term application of these measures produces a permanent correction of underlying metabolic or physiological abnormalities. Thus, a continuous long-term adherence to the prophylactic programme is required to achieve prevention of new stone formation.

The above factors should be carefully considered and discussed with the patient before beginning treatment. The type and the rigorousness of medical treatment depend on a variety of factors, including the severity of stone disease (single or recurrent and recent activity) (Hosking et al 1983), presence of extrarenal manifestations (Pak 1982), availability of selective treatment programme (Pak et al 1981a), effectiveness and safety of such a programme, and anticipated patient compliance to a long-term treatment programme. Patients with a single stone episode or inactive disease could be managed conservatively with high fluid intake and avoidance of dietary excesses (Hosking et al 1983). More aggressive treatments involving drugs may be indicated for those with active stone disease and for certain patients with a single stone episode who are at increased risk of developing others. In such patients, we recommend that specific treatments be selected or 'tailor made' for each cause of stone disease in order to correct the underlying derangement(s). In patients with extrarenal manifestations as well as stone disease, selective treatments may have an additional value in overcoming these non-stone manifestations. However, a successful outcome depends on rigid long-term adherence to the recommended programme. It requires a commitment of the physician to follow patients long-term, monitor effectiveness of treatment and search for hazards of therapy.

CONSERVATIVE MANAGEMENT OF NEPHROLITHIASIS

It is recommended that conservative measures (high fluid intake and avoidance of dietary excesses) be applied in all patients with nephrolithiasis (Pak et al 1984). They may be applied alone in patients with a single stone episode and inactive stone disease, especially in the absence of extrarenal manifestations. They should be applied together with a specific medical treatment program in patients with recurrent active stone disease, particularly if extrarenal manifestations are present.

Effectiveness of conservative therapy

Available literature suggests that an application of conservative therapy could considerably delay the development of the second stone in patients with single stone episodes (Hosking et al 1983). In patients with mild–moderate severity of stone disease, a review of 11 conservative or placebo trials indicated that stone formation declined from 0.54 to 0.25 stones/patient year, and that around 61% of patients were in remission (stopped forming stones) (Preminger et al 1985a).

Specifics and objectives of conservative treatment

Some conservative programmes are applicable to all forms of stone disease, whereas others are useful for particular causes. It is apparent that the extent to which certain dietary indiscretion contributes to stone formation often depends on the particular physiological derangement identified. Thus, some dietary modifications should not be made universally, but selectively applied according to the cause of stone disease. Inappropriately used dietary change may be ineffective or may cause harm.

High fluid intake. High fluid intake is the only nutritional modification that is universally agreed to be useful in all forms of nephrolithiasis (Pak et al 1981b). By increasing urine output, urinary concentration of constituent ions and the saturation of stone-forming salts are lowered. Although this action may be opposed by a concurrent dilution of urinary inhibitors, the available data have not shown a loss of inhibitor activity. High fluid intake has been reported to increase renal oxalate excretion (Zarembski & Hodgkinson 1969). However, such an increase is modest, occurs at a relatively low urine output and is generally overcome by the effect of urinary dilution.

The objective of treatment is to drink a sufficient amount of fluid to achieve a minimum urine output of 2 litres per day. During normal activity, approximately 3 litres of fluid must be drunk daily to reach this goal. A higher intake is required when there is excessive sweating or gastrointestinal fluid loss. Fluid intake should be distributed throughout the day to assure a consistently high urine output. Any form of fluids is acceptable, except for milk products and tea in certain conditions (to be described later). Although certain fruit juices may contain oxalate, the beneficial effect of the provision of fluid predominates over the potential increase in oxalate absorption. There is probably no special virtue for cranberry juice, since the purported prophylactic value of this product may be accountable by the volume effect.

Ideally, the patient should develop a habit of drinking two glasses (600 ml) of fluid with every meal, one glass between meals and at bedtime and, if up at night to urinate, one to two glasses of fluids. If 50% of the fluid is taken as water then the other half can be fluids of the patient's choosing. Asking patients to collect a 24-hour urine to measure volume on the increased fluid intake provides a way for the patients and their physicians to determine continuing compliance.

Dietary oxalate restriction. Although dietary restriction of oxalate may be beneficial in any case of nephrolithiasis, it is particularly indicated when there is increased intestinal absorption of oxalate. In absorptive hypercalciuria intestinal absorption and renal excretion of oxalate may be increased with an excretion rate of oxalate of up to 60 mg per 24 hours. The high intestinal calcium absorption may not leave a sufficient amount of calcium to complex oxalate in the intestinal tract and prevent its absorption. This problem becomes more serious when the intraluminal content of calcium is reduced further by dietary calcium restriction or by oral administration of a calcium-binding agent, such as sodium cellulose phosphate (Pak 1981). Dietary oxalate restriction should be imposed simultaneously if a low calcium diet is instituted, particularly in patients with absorptive hypercalciuria. In all of these conditions, dietary oxalate restriction may retard stone formation by reducing urinary oxalate and the saturation of calcium oxalate.

Approximately 10% of the oxalate excreted in urine comes from the diet, with the remainder coming from endogenous metabolism. That portion of dietary oxalate that is absorbed and excreted in the urine depends upon its bioavailability. The bioavailability implies that only a portion of oxalate in the particular foodstuff may be available for intestinal absorption (Brinkley et al 1981). Unfortunately, the nutritional tables for oxalate need further updating and oxalate bioavailability has been only scarcely approached. Nevertheless, only a moderate oxalate restriction is generally necessary in controlling hyperoxaluria in patients with absorptive hypercalciuria. The patients are asked to avoid dark green roughages (such as spinach), rhubarb, brewed or 'sun' tea, chocolate and nuts. Ascorbic acid (vitamin C) supplementation > 1 g per day is discouraged because this vitamin is a substrate for oxalate synthesis. A more rigid oxalate restriction may be imposed if the aforementioned program is ineffective.

Dietary calcium restriction. Rigid calcium restriction (< 400 mg per day) is ill-advised, even in patients with absorptive hypercalciuria who have a high intestinal calcium absorption, since it is difficult to follow, may adversely affect general nutrition and may cause negative calcium balance. However, a moderate calcium restriction (400–600 mg per day) may be useful in absorptive hypercalciuria, since it alone may control the hypercalciuria in the type II presentation (Pak et al 1981a), or permit reduction of the dosage of medication necessary to restore normal urinary calcium in the type I presentation. A concurrent oxalate restriction is required as previously discussed.

Calcium restriction is neither necessary nor indicated in patients with nephrolithiasis with *normal* intestinal absorption of calcium. However, an excessive intake of calcium (> 1 g per day) should be avoided in these patients, since it may produce hypercalciuria of sufficient magnitude to be harmful to stone disease even when intestinal calcium absorption is normal.

The dietary restriction of calcium may be effective in patients with calcium nephrolithiasis by reducing the urinary excretion of calcium and the saturation of calcium salts, if the opposing stimulation of oxalate excretion is prevented by simultaneous oxalate restriction. A diet containing 400–600 mg of calcium per day may be followed by the patient with relative ease without impairing general nutrition by the avoidance of dairy products and excessive amounts of dark green vegetables.

Dietary sodium restriction. A high sodium intake may contribute to calcium stone formation by augmenting renal excretion of calcium and by producing sodium urate-induced crystallization of calcium salts, although the pathogenetic significance of the latter mechanism has not been clearly determined. The induced hypercalciuria may cause secondary hyperparathyroidism.

Two additional potential problems with a high sodium intake should be mentioned for completeness. First, a high sodium load may reduce urinary citrate excretion, thereby lowering the inhibitor activity against crystallization of calcium salts. Second, a high sodium intake attenuates the hypocalciuric action of thiazide (Brickman et al 1972) and exaggerates thiazide-induced hypokalaemia and hypocitraturia (Nicar et al 1984).

To overcome the aforementioned complications, a modern sodium restriction (100 mEq per day, or 5.85 g sodium chloride) may be helpful in all patients with idiopathic calcium urolithiasis. It may be indicated particularly in patients with hypercalciuria. A moderate sodium restriction usually may be achieved by the avoidance of obviously salty foods, prepared broths and soups rich in sodium, processed vegetables and by restricting the use of the salt shaker at mealtime. Salt substitutes may be used. If the urinary excretion of calcium can be reduced by salt restriction, then the patient will be benefited by reducing the saturation of calcium salts in the urine.

Dietary restriction of animal proteins. Excessive ingestion of foods rich in animal proteins (meat, poultry and fish) may increase urinary uric acid (from purine load) (Coe 1978), lower urinary pH and citrate (from high acid ash content), and increase urinary calcium (probably from high sulphate content and the reduction of renal tubular reabsorption of calcium from the acid load) (Breslau et al 1988). There may be an increased risk for uric acid lithiasis from high urinary uric acid and low urine pH and for calcium nephrolithiasis because of high urinary calcium and uric acid, and low urinary citrate.

In patients with an excessive intake of animal proteins, a moderate limitation of animal protein ingestion may be attempted, for example by omitting animal protein products in one meal each day or reducing the size of such servings. A more rigid restriction of animal proteins is often not practical. The virtue of a vegetarian diet over a meat diet, with respect to protection against stone formation, has not been established. The institution of a vegetarian diet may induce other alterations in the urine, including increased oxalate excretion that may oppose the beneficial effects of reduced calcium and uric acid and of increased urinary citrate and pH. At this point it would seem important to eliminate dietary excesses of protein (> 1.7 g per kg body weight per day) in patients with calcium nephrolithiasis.

Dietary phosphate restriction. The dietary restriction of phosphate-rich foods has been recommended for the control of infection (magnesium ammonium phosphate or struvite stones) on the premise that the resulting decline in urinary phosphate would lower urinary supersaturation of magnesium ammonium phosphate (Shorr & Carter 1950). However, this type of dietary restriction should not be imposed on patients with nephrolithiasis who form struvite stones secondarily from infection of the urinary tract with urea-splitting organisms. The changes induced by phosphate restriction in such patients could aggravate stone formation. These changes include increased hypercalciuria (from stimulated intestinal calcium absorption) and reduced complexation of calcium in the urine with increased free calcium ion activity in the urine (due to reduced phosphate excretion). If this dietary modification is sufficiently severe, the phosphorus depletion syndrome may result with the development of myopathy and osteomalacia (Lotz et al 1968).

Dietary adjustments as adjuncts to specific medical treatment

In those patients with nephrolithiasis whose stone formation has not been controlled by conservative means, including increased fluid intake and elimination of dietary excesses, the stone formation is considered active requiring specific medical treatment (Pak et al 1981a). With some of these treatment programmes, specific dietary restrictions may be indicated. Increased fluid intake as described previously should be continued with all medical treatment programmes, since the benefit gained in terms of reduced urinary concentration of solute and saturation will decrease the amount of medication needed in many of the patients. Sodium restriction is often necessary in patients who require thiazides for the control of hypercalciuria. If the dietary sodium is high (> 100 mEq per day), the hypocalciuric action of thiazide can be attenuated. When cellulose phosphate is used in the treatment of absorptive hypercalciuria, dietary restriction of oxalate is critical to the success of the programme as mentioned previously (Pak 1981). When this precaution has not been followed, along with magnesium supplementation and moderate calcium restriction, cellulose phosphate may have limited effectiveness in controlling stone formation. When allopurinol is used to treat hyperuricosuria, reduced intake of animal protein ahould be continued if possible. With the use of orthophosphate as the neutral salt, no specific dietary restrictions have been identified, although continued use of high fluid intake and elimination of dietary excesses would be advisable.

SELECTIVE THERAPY OF NEPHROLITHIASIS

Elucidation of the pathophysiology and formulation of diagnostic criteria for different causes of nephrolithiasis have made feasible the adoption of selective or optimal treatment programmes (Pak 1982, Pak et al 1981a). Such programmes should (a) reverse the underlying physicochemical and physiological derangements, (b) inhibit new stone formation, (c) overcome non-renal complications of the disease process, and (d) be free of serious side effects. The rationale for the selection of certain treatment programmes is the assumption that the particular physicochemical and physiological aberrations identified with the given disorder are aetiologically important in the formation of renal stones (as previously discussed), and that the correction of these disturbances will prevent stone formation. Moreover, it is assumed that such a selected treatment programme would be more effective and safer than a 'random' treatment. Despite a lack of conclusive experimental verification, these hypotheses appear reasonable and logical.

We would recommend that selective therapy be applied initially in patients with active stone disease who have definable physiological abnormalities amenable to correction by medical treatment. Selective treatment would also be indicated in patients who continue to form stones on conservative treatment.

The following is our own recommendation for the selective treatment approach (Table 12.1). Supporting data are drawn largely from our own work, mainly for the sake of convenience. Mechanism of drug action will be summarized and clinical responsiveness reviewed.

Table 12.1 Selective treatment programme

Condition	Treatment	Physiological action	Physicochemical action
Absorptive hypercalciuria type I	Sodium cellulose phosphate	↓ Intestinal Ca absorption ↓ Urinary Ca	↓ Urinary saturation of Ca oxalate ↓ Brushite saturation
Absorptive hypercalciuria type II	Low Ca diet	↓ Intestinal Ca absorption ↓ Urinary Ca	↓ Urinary saturation of Ca oxalate and brushite
Renal hypercalciuria	Thiazide	↓ Urinary Ca (sustained) ↓ Intestinal Ca absorption	↓ Urinary saturation of Ca salts
Primary hyperparathyroidism	Parathyroidectomy	↓ PTH ↓ Urinary Ca	↓ Urinary saturation of Ca salts ↑ Inhibitor activity
Renal phosphate leak	Orthophosphate	↓ 1, 25-$(OH)_2D$ ↓ Intestinal Ca absorption ↓ Urinary Ca ↑ Urinary citrate and pyrophosphate	↓ Urinary saturation of of Ca oxalate ↑ Inhibitor activity
1, 25-$(OH)_2D$ excess and combined defect	Thiazide	↓ Urinary Ca	↓ Urinary saturation of Ca salts
Hyperuricosuric Ca nephrolithiasis	Allopurinol	↓ Urinary uric acid	↓ Urate-induced crystallization of Ca salts
	Potassium citrate	↑ Urinary citrate	↓ Urinary saturation of Ca oxalate ↓ Urate-induced crystallization of Ca salts
Enteric hyperoxaluria	↓ Oxalate intake	↓ Urinary oxalate	↓ Urinary saturation of Ca oxalate
	Potassium citrate	↑ Urinary citrate ↑ Urinary pH	↓ Urinary saturation of of Ca oxalate ↑ Inhibitor activity
	Magnesium citrate	↑ Urinary Mg and citrate	↓ Urinary saturation of Ca oxalate
Hypocitraturic Ca nephrolithiasis	Potassium citrate	↑ Urinary citrate ↑ Urinary pH	↓ Urinary saturation of Ca oxalate ↑ Inhibitor activity
Gouty diathesis	Potassium citrate	↑ Urinary pH ↓ Undissociated uric acid	↓ Urinary saturation of uric acid
Cystinuria	D-penicillamine or MPG	Mixed disulphide with cysteine ↓ Urinary cystine	↓ Urinary saturation of cystine
Infection stones	Acetohydroxamic acid	↓ Urease activity ↓ NH_4^+ ↓ pH	↓ Urinary saturation of struvite
Low urine volume	High fluid intake	↑ Urine volume	↓ Urinary saturation of stone-forming salts

Sodium cellulose phosphate for absorptive hypercalciuria type I

There is currently no treatment programme which is capable of correcting the basic abnormality of absorptive hypercalciuria type I, although several drugs are available that have been shown to restore normal calcium excretion. Sodium cellulose phosphate best meets the criteria for optimum therapy (Pak 1981, Pak et al 1974). When given orally, this non-absorbable, ion-exchange-resin binds calcium and inhibits calcium absorption. However, this inhibition is caused by limiting the amount of intraluminal calcium available for absorption and not by correcting the basic disturbance in calcium transport.

The above mode of action accounts for the three potential complications of sodium cellulose phosphate therapy (Pak 1981). First, it may cause negative calcium balance and parathyroid stimulation if it is used in patients with normal intestinal calcium absorption, or with renal or resorptive hypercalciuria. Second, the treatment may cause magnesium depletion by binding magnesium as well. Third, sodium cellulose phosphate may produce secondary hyperoxaluria, by binding divalent cations in the intestinal tract, reducing divalent cation–oxalate complexation, and making more oxalate available for absorption. These complications may be overcome by using the drug only in documented cases of absorptive hypercalciuria type I, applying oral magnesium supplementation (magnesium citrate 10 mEq twice daily, separately from sodium cellulose phosphate), and by imposing a moderate dietary restriction of oxalate.

When the above precautions are followed (Pak 1981), sodium cellulose phosphate at a dosage of 10–15 g/day (given with meals) has been shown to reduce urinary calcium and the saturation of calcium salts (calcium phosphate as well as calcium oxalate), maintain stable bone density and to be clinically effective. In our experience, this treatment has reduced the stone formation rate from 2.28 stones/patient year to 0.23/patient year $P < 0.001$ by the chi-square test), caused remission in 77.8% of patients and lowered individual stone formation rate in all patients.

Reduced calcium intake in absorptive hypercalciuria type II

The features of absorptive hypercalciuria type II (Pak et al 1980) are identical to those of absorptive hypercalciuria type I, except that normocalciuria (< 200 mg/day) can be induced by a diet of 400 mg calcium and 100 mEq sodium/day. In addition, many patients show disdain for drinking fluids and thus excrete concentrated urine. A low calcium intake (400–600 mg/day) and high fluid intake (sufficient to achieve a minimum urine output of greater than 2 litres/day) would seem ideally indicated, since normocalciuria could be restored by dietary calcium restriction alone, and increased urine volume has been shown to reduce urinary saturation of calcium oxalate, brushite, and monosodium urate, and inhibit spontaneous nucleation of calcium oxalate (Pak et al 1981b).

In 24 patients so treated, the stone formation rate decreased from 1.83 to 0.38 stones/patient year ($P < 0.001$), 70.8% of patients were in remission over a mean follow-up of 2.32 years/patient, and individual stone formation declined in 22 patients (91.7%).

Thiazide for renal hypercalciurias

Thiazide is ideally indicated for the treatment of renal hypercalcuria (Pak 1979a). This diuretic has been shown to correct the renal leak of calcium by augmenting calcium reabsorption in the distal tubule directly, and by causing extracellular volume depletion and stimulating proximal tubular reabsorption of calcium. The ensuing correction of secondary hyperparathyroidism restores normal serum 1, 25-$(OH)_2D$ and intestinal calcium absorption. In a recent study, thiazide has been shown to produce a sustained correction of hypercalciuria commensurate with a restoration of normal serum 1, 25-$(OH)_2D$ and intestinal calcium absorption during up to 10 years of therapy (Preminger & Pak 1987).

Physicochemically, the urinary environment becomes less saturated with respect to calcium oxalate and brushite during thiazide treatment, largely because of the reduced calcium excretion (Pak & Galosy 1980). Moreover, urinary inhibitor activity, as reflected in the limit of metastability (Pak & Galosy 1980), is increased by an unknown mechanism. These effects are shared by hydrochlorothiazide 50 mg twice daily, chlorthalidone 50 mg/day or trichlormethiazide 4 mg/day. Potassium supplementation may sometimes be required to prevent hypokalaemia and attendant hypocitraturia. Potassium citrate (15–20 mEq twice/day) has been shown to be effective in averting hypokalaemia and in increasing urinary citrate, when administered to patients with calcium nephrolithiasis taking thiazide (Nicar et al 1984, Pak et al 1985b). Concurrent use of triamterene, a potassium-sparing agent, should be undertaken with caution because of recent reports of triamterene stone formation (Ettinger et al 1980). Amiloride may be used with thiazide, since it alone has sometimes been shown to exert a hypocalciuric action, to exaggerate the hypocalciuric action of thiazide and to prevent hypokalaemia (Leppla et al 1983). However, amiloride itself does not augment citrate excretion. Thus, in patients with hypercalciuric nephrolithiasis presenting with hypocitraturia in whom the use of potassium citrate is contemplated, it is probably wise to use thiazide alone without a potassium-sparing diuretic.

During this treatment, stone formation decreased from 1.83 stones/patient year to 0.40/patient year ($P < 0.001$), and remission was encountered in 75% of patients.

Non-selective treatment for hypercalciurias

Thiazide for absorptive hypercalciuria type I. Thiazide is not considered a selective therapy for absorptive hypercalciuria, since it does not decrease intestinal calcium absorption in this condition (Pak 1979a). However, this drug has been widely used to treat this disorder, because of its hypocalciuric action and the high cost and inconvenience of alternative therapy (sodium cellulose phosphate).

Our studies indicate that thiazide may have a limited long-term effectiveness in absorptive hypercalciuria type I (Preminger & Pak 1987). Despite an initially reduced calcium excretion, the intestinal calcium absorption persistently remains elevated (Pak 1979a). Preliminary studies suggest that the retained calcium may be accreted in bone, at least during the early years of therapy (Pak et al 1982). Bone density, determined in the distal third of the radius by single photon absorptiometry, increased significantly during thiazide treatment in absorptive hypercalciuria, with an annual increment of 1.34%. With continued treatment, however, the rise in bone density stabilizes, and the hypocalciuric effect of thiazide becomes attenuated. The results suggest that thiazide treatment may cause a low turnover state of bone, which interferes with a continued calcium accretion in the skeleton. The 'rejected' calcium would then be excreted in urine. In contrast, bone density was not significantly altered in renal hypercalciuria where thiazide was shown to cause a decline in intestinal calcium absorption commensurate with a reduction in urinary calcium.

Thus, thiazide is often ineffective in correcting hypercalciuria in absorptive hypercalciuria after more than two years of treatment (Preminger & Pak 1987). Another problem with thiazide is the induction of hypocitraturia previously enumerated (Nicar et al 1984). Probably owing to these changes, thiazide has been shown to be relatively ineffective in the management of stone disease in patients with absorptive hypercalciuria type I (Fig. 12.1).

Practical guidelines in the use of thiazide or sodium cellulose phosphate. It is recognized that sodium cellulose phosphate does not correct the basic intestinal calcium transport defect in absorptive hypercalciuria type I and that thiazide treatment is attendant with certain complications. We recommend the following guidelines in the use of these two agents until more selective therapies are found.

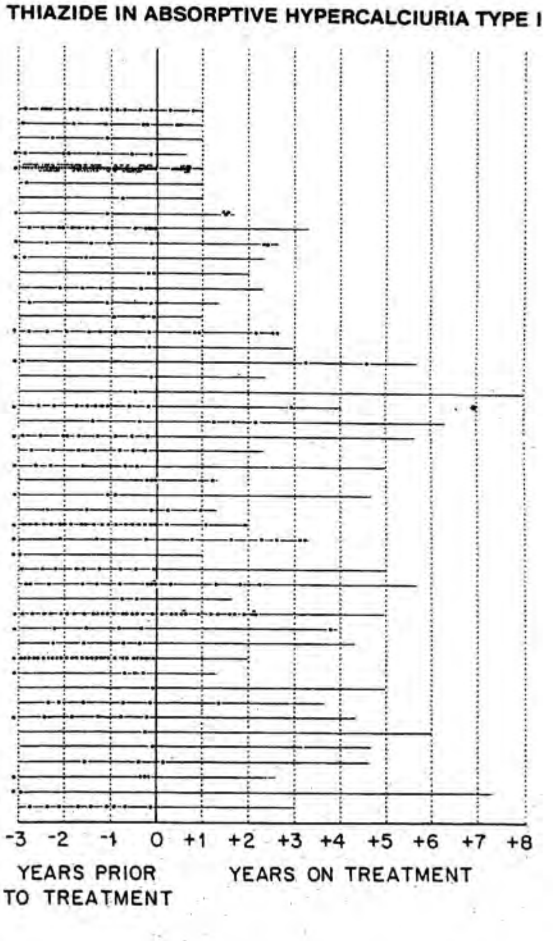

Fig. 12.1

Effect of thiazide therapy on new stone formation in patients with absorptive hypercalciuria type I. Each line represents a study in a separate patient. Each circle indicates a new stone episode. Onset of thiazide treatment is at time zero. Asterisk before the line represents patient who had pre-existing stones when the treatment was begun.

We recommend that sodium cellulose phosphate be used in patients with severe absorptive hypercalciuria type I (urinary calcium > 350 mg/day), or those resistant to, or intolerant, of thiazide therapy. In patients with absorptive hypercalciuria type I who may be at risk for bone disease (growing children, elderly patients, or postmenopausal women), thiazide might be the first choice. When thiazide becomes ineffective in lowering urinary calcium, this treatment may be temporarily substituted by sodium cellulose phosphate or orthophosphate (for approximately 6 months). Restoration of hypocalciuric response to thiazide generally ensues then, permitting resumption of thiazide therapy. Thiazide would of course be the treatment of choice for renal hypercalciuria.

We would recommend that potassium citrate (e.g. 15–20 mEq twice/day) always be used with thiazide (e.g. hydrochlorothiazide 50 mg twice/day) in order to prevent hypokalaemia and augment citrate excretion (Pak et al 1985b).

Parathyroidectomy for primary hyperparathyroidism

There is no established medical treatment for the nephrolithiasis of primary hyperparathyroidism. Although orthophosphates have been recommended for disease of mild–moderate severity (Broadus et al 1983), their safety or efficacy has not yet been proven. They should be used only when parathyroid surgery cannot be undertaken.

Oestrogen is a reasonable alternative in postmenopausal women with primary hyperparathyroidism in whom surgery is refused or contraindicated (Gallagher & Nordin 1972, Selby & Peacock 1986). This treatment (e.g. conjugated oestrogen 0.625 mg/day, 25 days of each month), has been shown to reduce serum calcium concentration (by inhibiting PTH-induced bone resorption) and thereby reduce urinary calcium.

Parathyroidectomy is the optimal treatment for the nephrolithiasis of primary hyperparathyroidism. Following removal of abnormal parathyroid tissue, urinary calcium is restored to normal commensurate with a decline in serum concentration and in intestinal calcium absorption (Kaplan et al 1976). The urinary environment becomes less saturated with respect to calcium oxalate and brushite and its limit of metastability (formation product ratio) for these calcium salts increases (Pak 1979b). There is typically a reduced rate of new stone formation, unless urinary tract infection is present. Parathyroidectomy is contraindicated in secondary hyperparathyroidism of renal hypercalciuria and in absorptive hypercalciuria.

Treatment of fasting hypercalciuria with normal parathyroid function

Orthophosphate for absorptive hypercalciuria type III (phosphate leak). Orthophosphate (neutral or alkaline salt of sodium and/or potassium, 0.5 g phosphorus three to four times/day) would seem to be the logical treatment because of its potential for the inhibition of 1, 25-$(OH)_2D$ synthesis (Barilla et al 1979). However, there is currently no convincing evidence that this treatment restores normal intestinal calcium absorption in this condition. Orthophosphate reduces urinary calcium probably by directly enhancing the renal tubular reabsorption of calcium. Urinary phosphorus is markedly increased during therapy, a finding reflecting the absorbability of soluble phosphate. Physicochemically, orthophosphate reduces urinary saturation of calcium oxalate, but increases that of brushite (Pak & Galosy 1980). Moreover, the urinary inhibitor activity is increased, probably owing to the stimulated renal excretion of pyrophosphate and citrate. Although contrary reports have appeared, this treatment programme has been reported to cause soft tissue calcification and parathyroid stimulation (Dudley & Blackburn 1970). It is contraindicated in nephrolithiasis complicated by urinary tract infection.

In our experience, orthophosphate treatment lowered stone formation from 2.38 stones/patient year to 0.36/patient year ($P < 0.001$), produced a remission in 62.5% of patients over a mean follow-up of 4.13 years/patient, and caused a reduced stone formation rate individually in all patients.

Primary 1, 25-$(OH)_2D$ excess. There is no known treatment which is capable of correcting this disturbance. Adrenocorticosteroids do not reduce serum 1, 25-$(OH)_2D$ or calcium absorption in hypercalciuric nephrolithiasis, unlike in sarcoidosis (Zerwekh et al 1980). While orthophosphate has been shown to reduce serum 1, 25-$(OH)_2D$, our limited studies indicated persistent hyperabsorption of calcium from the intestinal tract (Barilla et al 1979).

Since the skeleton may be adversely affected due to the bone resorptive capacity of 1, 25-$(OH)_2D$, thiazide may be preferable to sodium cellulose phosphate in controlling hypercalciuria. Eventual attenuation of the hypocalciuric action to thiazide is likely as in absorptive hypercalciuria type I. In that event, thiazide may be temporarily substituted with orthophosphate or sodium cellulose phosphate.

Combined disturbance in renal proximal tubular function. Since renal calcium leak is presumed to be an invariant feature, coexisting with either phosphate leak or excessive 1, 25-$(OH)_2D$ synthesis, thiazide should be attempted first. If this treatment is ineffective in controlling hypercalciuria, or should hypercalcaemia develop, orthophosphate or sodium cellulose phosphate may be added to the treatment programme.

Allopurinol for hyperuricosuric calcium oxalate nephrolithiasis
Allopurinol (300 mg/day) is the physiologically meaningful drug of choice in hyperuricosuric calcium oxalate nephrolithiasis resulting from uric acid overproduction, because of its ability to reduce uric acid synthesis and lower urinary uric acid (Coe 1978). Its use in hyperuricosuria associated with dietary purine overindulgence is also reasonable, since dietary purine restriction is often impractical. Physicochemical changes ensuing from restoration of normal urinary uric acid include an increase in the urinary limit of metastability of calcium oxalate (Pak et al 1978a). Thus, the spontaneous nucleation of calcium oxalate is retarded by treatment, probably via inhibition of monosodium urate-induced stimulation of calcium oxalate crystallization (Pak et al 1979). Because of the potential exaggeration of monosodium urate-induced calcium oxalate crystallization from excessive sodium intake, a moderate sodium restriction (< 150 mEq/day) is also advisable.

In our study involving a mean allopurinol treatment period of 2.28 years/patient, stone formation rate decreased from 1.00 stone/patient year to 0.09/patient year ($P < 0.001$), 83.3% of patients were in remission and individual stone formation was reduced in 95.8% of patients. In a randomized study, allopurinol has been shown to reduce recurrent formation of calcium oxalate stones (Ettinger et al 1986).

Potassium citrate represents an effective alternative to allopurinol in the treatment of this condition (Pak & Peterson 1986). Citrate added to a synthetic medium metastably supersaturated with respect to calcium oxalate, was shown to inhibit the heterogeneous nucleation of calcium oxalate by monosodium urate (Pak & Peterson 1986). When potassium citrate (60 mEq/day in divided doses) was given to patients with hyperuricosuric calcium oxalate nephrolithiasis, urinary citrate rose by 249–402 mg/day to approximate the normal mean value of 643 mg/day. Thus, the induced hypercitraturia not only reduced urinary saturation of calcium oxalate (by complexing calcium), but also inhibited urate-induced crystallization of calcium oxalate. This treatment has been shown to reduce the stone formation rate from 1.55 ± 2.70/patient year to 0.38 ± 1.22/patient year ($P < 0.01$) and produce a remission in 84.2% of patients.

Potassium citrate may be particularly useful in patients with mild–moderate hyperuricosuria (< 800 mg/day) in whom hypocitraturia is also present. However, allopurinol is probably preferred in patients with more marked hyperuricosuria, especially if hyperuricaemia coexists.

Treatment of enteric hyperoxaluria
The cause for stone formation is multifactorial. The treatment should therefore be directed at correcting the various disturbances present, including hyperoxaluria, hypocitraturia and low urinary pH, hypomagnesiuria and low urine volume.

Oral administration of large amounts of calcium (0.25–1.0 g four times/day) or magnesium has been recommended for the control of calcium nephrolithiasis of ileal disease. Although urinary oxalate may decrease (probably from binding of oxalate by divalent cations), the concurrent rise in urinary calcium may obviate the beneficial effect of this therapy, at least in some patients (Barilla et al 1978). Cholestyramine does not cause a sustained reduction in oxalate excretion. A limitation of dietary oxalate intake and partial replacement of dietary fat with medium chain fatty acids may be helpful in those patients who also have malabsorption.

The treatment of low urinary citrate and pH with potassium will be considered in the next section under Chronic diarrhoeal states. Hypomagnesiuria is due to impaired intestinal absorption of magnesium. It contributes to calcium oxalate stone formation because of reduced complexation of oxalate by magnesium and consequent rise in the urinary saturation of calcium oxalate. Oral magnesium supplementation could partially correct hypomagnesiuria although it may provoke further diarrhoea. In our experience, magnesium citrate (20–40 mEq/day in divided doses) is better absorbed and tolerated than magnesium oxide or hydroxide (Lindberg et al 1990). Magnesium chloride is contraindicated since it will exaggerate metabolic acidosis.

A high fluid intake is recommended to assure adequate urine volume. Control of excessive intestinal fluid loss with an antidiarrhoeal agent may be necessary before a sufficient urine output could be achieved.

Calcium citrate may theoretically have a role in the management of enteric hyperoxaluria. This treatment may lower urinary oxalate by binding oxalate in the intestinal tract. It may raise urinary citrate and pH by providing an alkali load (Harvey et al 1985). Finally, it may correct the malabsorption of calcium and adverse effects on the skeleton by providing an efficiently absorbed calcium.

Potassium citrate for hypocitraturic calcium nephrolithiasis
In 1985, the United States Food and Drug Administration approved potassium citrate for the treatment of calcium nephrolithiasis due to hypocitraturia of any aetiology, based largely on our work summarized below.

Renal tubular acidosis (distal) (Preminger et al 1985b). Since it is an alkali, potassium citrate therapy corrects metabolic acidosis and hypokalaemia. Moreover, it is capable of restoring normal urinary citrate, although large doses (up to 120 mEq/day) may be required in severe acidotic states. Urinary calcium typically declines with correction of acidosis. The overall rise in urinary pH is small, since urinary pH is high to begin with; the urinary pH is generally below 7.5 during treatment unless there is a complication by a urinary tract infection.

Thus, potassium citrate treatment produces a sustained decline in the urinary saturation of calcium oxalate (from reduction in urinary calcium and in citrate complexation of calcium). The urinary saturation of calcium phosphate does not increase because the rise in phosphate dissociation is relatively small (due to a modest rise in pH) and is adequately compensated by a decline in ionic calcium concentration. Moreover, inhibitor activity against the crystallization of calcium oxalate and calcium phosphate is augmented due to the direct action of citrate (see Ch. 10).

Nine patients with incomplete distal renal tubular acidosis received potassium citrate (60–80 mEq/day) (Preminger et al 1985b). Six patients did not form further stones. Three patients continued to pass stones. For this analysis, these stones passed were considered to be newly formed, although they most likely represented passage of pre-existing stones. Using this assumption, remission rate was 66.7%, stone formation rate declined individually in all 9 patients, and group mean stone formation rate declined by 91.2% upon institution of potassium citrate therapy.

Chronic diarrhoeal states. In patients with mild–moderate severity of intestinal fluid loss in whom hypocitraturia is not severe (urinary citrate being in the range of 100–300 mg/day), potassium citrate (40–60 mEq in three to four divided doses in a liquid form) is generally effective in restoring normal urinary citrate and pH. Urinary calcium generally remains low. In those with severe hypocitraturia (with urinary citrate < 100 mg/day), even excessive doses of potassium citrate (up to 120 mEq/day) may be ineffective in restoring normal urinary citrate.

In our trial, potassium citrate therapy reduced stone formation rate from 4.69 ± 10.12 to 0.71 ± 1.44 stones/patient year ($P < 0.01$) and produced remission in 70% of patients (Pak et al 1985a).

We recommend that a liquid preparation of potassium citrate be used rather than a slow-release tablet preparation in these states, because some of these patients may have intestinal adhesions and may be more prone to obstruction from a tablet preparation. Furthermore, a slow-release medication may be poorly absorbed owing to rapid intestinal transit.

We suggest a frequent dose schedule (three to four times/day) for the liquid preparation because of relative short duration of biological action. In all other conditions, the solid slow-release preparation may be used. A less frequent dose schedule (twice/day) is acceptable for the solid preparation because of its slow release characteristic.

Thiazide-induced hypocitraturia. Hypokalaemia resulting from thiazide may cause hypocitraturia probably by causing intracellular acidosis and may thereby attenuate the beneficial hypocalciuric effect of therapy on renal stone formation (Nicar et al 1984, Pak et al 1985b).

It has been suggested that potassium citrate may be less effective than potassium chloride in correcting the thiazide-induced hypokalaemia, because of the poor reabsorbability of citrate from the renal tubules (Kassirer et al 1965). However, in 13 patients with calcium oxalate nephrolithiasis taking thiazide, who were randomized into potassium citrate and potassium chloride supplementation at equivalent dosages, potassium citrate was equally effective as potassium chloride in correcting thiazide-induced hypokalaemia (Nicar et al 1984). Moreover, the addition of potassium citrate to thiazide therapy raised urinary pH and citrate.

Thirteen patients with hypercalciuric calcium oxalate nephrolithiasis (11 with absorptive and 2 with renal hypercalciuria) continued to form calcium stones (principally calcium oxalate) when treated with thiazide (5.12 ± 10.87 stones/patient/year) (Pak et al 1985b). Because they had hypocitraturia (250 ± 86 mg/day vs 643 ± 236 mg/day in normal subjects), potassium citrate (10–20 mEq three times/day) was added to the ongoing thiazide treatment. During combined treatment with potassium citrate and thiazide, 10 patients stopped forming new stones and all 13 had a reduced stone formation rate (Fig. 12.2).

Idiopathic hypocitraturic calcium oxalate nephrolithiasis. (Pak & Fuller 1986). This entity, idiopathic hypocitraturic calcium oxalate nephrolithiasis, includes hypocitraturia occurring alone with calcium stones and hypocitraturia occurring in conjunction with absorptive and renal hypercalciurias and hyperuricosuric calcium oxalate nephrolithiasis. Stones formed are predominantly composed of calcium oxalate.

Potassium citrate treatment produced a sustained increase in urinary citrate excretion from initially low values (223–253 mg/day) to within normal limits (470–620 mg/day) (Pak & Fuller 1986). Urinary pH rose significantly and was maintained at 6.5–7.0. Along with these changes, the urinary saturation of calcium oxalate declined significantly to normal limits. Further stone formation ceased in 89.2% of patients during treatment, and the stone formation rate declined from 2.11 ± 5.68 to 0.28 ± 1.30 stones/patient year ($P < 0.01$) (Fig. 12.3).

Potassium citrate for gouty diathesis
In this condition, urinary pH is typically less than 5.5 (Pak et al 1986b, Pak 1987a). Some patients with uric acid lithiasis may sometimes form mixed stones with calcium oxalate and may occasionally form predominantly calcium oxalate stones.

In general, the maintenance of urinary pH between 6–7 is desirable for the control of uric acid lithiasis and calcium oxalate nephrolithiasis. At such a pH range, the concentration of undissociated uric acid is expected to be low because most of the uric acid would be dissociated. Moreover, there would be an enhanced inhibitor activity of citrate and pyrophosphate because more of them would be in active ionic forms. Finally, ionized calcium concentration decreases as the pH rises, because of enhanced dissociation of phosphate and citrate and calcium complexation by these anions, thus reducing the saturation of calcium oxalate.

Potassium citrate treatment (30–60 mEq/day in divided doses) significantly increased urinary pH from the low mean value of 5.30 to above 6.19, but less than 7 (Pak et al 1986b). Owing to the resulting enhanced dissociation of uric acid, the amount of undissociated uric acid significantly decreased to the range encountered in normal subjects without stones (< 150 mg/day). Thus, potassium citrate therapy significantly increased the solubility of uric acid.

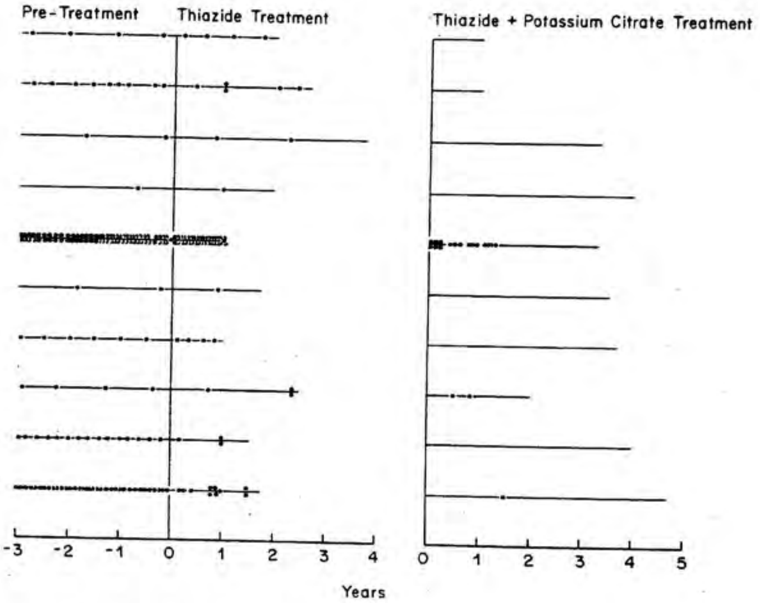

Fig. 12.2

Effect of thiazide treatment and of thiazide with postassium citrate on new stone formation. Combined thiazide and postassium citrate treatment was begun immediately after thiazide treatment.

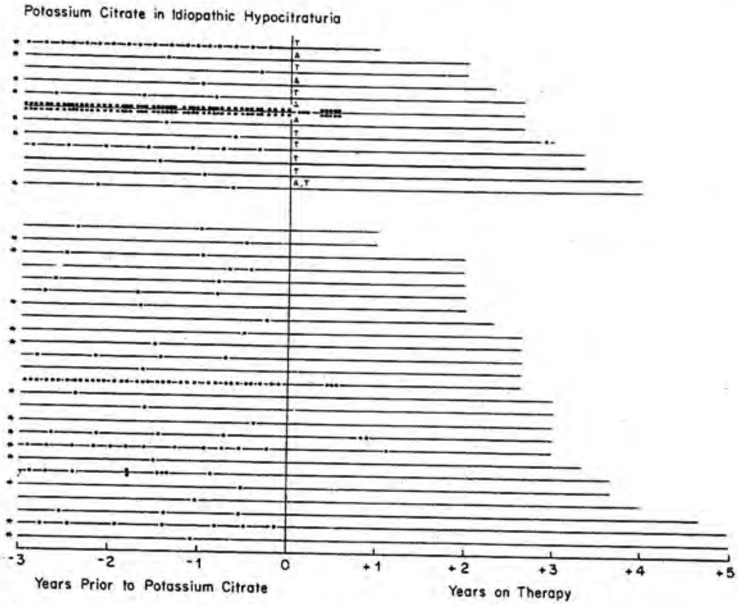

Fig. 12.3

Effect of potassium citrate therapy on new stone formation.

During potassium citrate therapy, the new stone formation rate declined from 1.25 ± 1.71 stones/year to 0.01 ± 0.04 stones/year ($P < 0.001$ by chi-square) (Pak et al 1986b). Remission was experienced in 94.4% of patients, and the group stone formation rate declined by 99.2%. Thus, this treatment is effective in preventing both uric acid and calcium nephrolithiasis.

It is apparent that potassium citrate could be used in a variety of conditions. The physiological and physicochemical actions of potassium citrate are summarized in Table 12.2.

Treatment of cystinuria (Pak 1987b) The goal of therapy is to reduce the urinary cystine concentration below its solubility limit. It may be accomplished by dietary means aimed at reducing cystine synthesis and excretion, conservative measures directed at decreasing cystine concentration or increasing cystine solubility, and by treatment with chelating agents which convert to a more soluble form.

Dietary manipulation. A low methionine diet has often been recommended for the control of cystine nephrolithiasis because of the well-known requirement of this essential amino acid for cystine production. While this dietary manoeuvre may reduce cystine excretion, a rigid methionine restriction is impractical. The compliance is often poor to a diet devoid or severely restricted in fresh meat, poultry, fish and dairy products. Moreover, there may be long-term adverse consequences of such a diet on other organ systems such as the skeleton. Thus, it is our practice to recommend avoidance of excessive intake of the above food items, but not necessarily severely to restrict them.

Table 12.2 Physiological and physicochemical effects of potassium citrate therapy

	Renal tubular acidosis	Hypocitraturic calcium oxalate nephrolithiasis	Gouty diathesis	Hyperuricosuric Ca nephrolithiasis
Urinary				
pH	Increase	Increase	Increase	Increase
Citrate	Increase	Increase	Increase	Increase
Calcium	Decrease	Transient decrease	Transient decrease	No change
Uric acid	No change	No change	No change	No change
Ca oxalate				
APR/RSR	Decrease	Decrease	Decrease	Decrease
FPR	Unknown	Unknown	Increase	Not tested
FPR/APR DS	Unknown	Unknown	Decrease	Not tested
PI	Increase	Increase	Increase	Increase
Uric acid				
Undissociated	Decrease	Decrease	Decrease	Decrease
Ca phosphate				
APR/RSR	Decrease	Increase	Increase	No change
Sodium urate				
APR/RSR	No change	No change	No change	No change
Induction of Ca oxalate crystallization	Inhibited	Inhibited	Inhibited	Inhibited

Abbreviations: APR activity product ratio, RSR relative saturation ratio, FPR formation product ratio, DS discriminant score, PI permissible increment. APR and RSR are measures of urinary saturation. FPR, DS and PI are indices of inhibitor activity.

Conservative measures. In patients with moderate cystinuria (250–500 mg/day) with cystine calculi, conservative measures of high fluid intake and alkali should be attempted first. The aim of fluid therapy is to increase urine volume sufficiently to reduce cystine solubility below the solubility limit. At least 3 litres of fluid (10 × 300 ml glassfuls) should be provided, including 2 glasses with each meal and at bedtime. The patients should be expected to awake at night to urinate; they should drink 2 more glasses of fluids before returning to bed. Additional fluids should be consumed if there is excessive sweating or intestinal fluid loss. A minimum urine output of 2 litres/day on a consistent basis should be sought, a goal attainable by most patients with proper and persistent instruction.

All types of fluid are generally permissible, with the possible exception of milk (with high methionine content) and brewed tea (with high oxalate content increasing risk for calcium oxalate nephrolithiasis which sometimes complicates cystine nephrolithiasis). Fruit juices (grapefruit, orange, cranberry, apple, grape) may be particularly advantageous, because they provide not only water but alkali. For example, 900 ml of orange juice (1 glassful with breakfast and again with dinner) may provide enough citrate to increase urinary pH by 0.5 unit.

The object of alkali therapy is to increase urinary pH to enhance cystine solubility. However, excessive alkali therapy is not indicated. A substantial increase in cystine solubility does not occur until the urinary pH exceeds 7.5.

The provision of alkali, no matter how much, rarely raises urinary pH above 7.5. When urinary pH increases above 7.0, with alkali therapy, the complication of calcium phosphate nephrolithiasis may ensue because of the enhanced urinary supersaturation of hydroxyapatite in an alkaline environment.

We recommend that a modest amount of alkali be provided in order to maintain urinary pH at a high normal range (6.5–7.0). Potassium alkali is more advantageous than sodium alkali, because it does not cause hypercalciuria and is less likely to cause the complication of calcium stones. Citrate is preferable to bicarbonate, because it produces a more constant and persistent elevation in urinary pH. The slow-release citrate preparation is probably superior to the readily available liquid preparation in this regard. It is our common practice to use potassium citrate (wax matrix tablets) at a dosage of 15–20 mEq twice/day. The dosage may be adjusted depending on the results of urinary pH.

D-Penicillamine. The object of D-penicillamine treatment is to reduce total cystine excretion by complexing cysteine, the monomeric form of cystine (Halperin et al 1981, Crawhall et al 1963). It may be added to the conservative treatment programme when the latter is ineffective in controlling stone formation in patients with moderate cystinuria. In patients with severe cystinuria ($>$ 500 mg/day), in whom the customary conservative programme alone is not likely to be effective, D-penicillamine therapy (*with* conservative measures) may be instituted from the start.

D-Penicillamine (BB-dimethyl-cysteine) shares with cysteine a free sulphydryl group. Thus, it readily undergoes thiol-disulphide exchange with cystine to form penicillamine-cysteine disulphide, which has a much higher aqueous solubility than cystine. Following oral administration, a sufficient amount of D-penicillamine could appear in urine to complex cysteine and thereby lower cystine excretion.

The dose of D-penicillamine should not be arbitrary, but should be based on that amount required to reduce urinary cystine concentration to below its solubility limit (generally $<$ 250 mg/litre). The extent of the decline in cystine excretion is proportional to the D-penicillamine dosage. Each increment in D-penicillamine dosage of 250 mg/day might be expected to reduce urinary cystine by 75–100 mg/day. Accordingly, assuming that a minimum desired urine output of 2 litres/day has been achieved, the minimum effective D-penicillamine dose might be 1250 mg/day when cystine excretion is 1000 mg/day, or 750 mg/day when urinary cystine is 800 mg/day. The medication is generally given in divided doses before meals, since its absorption may be impaired when mixed with certain foods.

There is substantial evidence that D-penicillamine can favourably modify the course of cystine nephrolithiasis. If adequate amounts of the drug could be given to lower urinary cystine to desired levels, one should expect a reduction in rates of stone passage and new stone formation. When there is a sufficient fall in cystine excretion to produce urinary undersaturation, dissolution of existing cystine stones could occur.

Unfortunately, a substantial number of patients develop adverse reactions to D-penicillamine treatment (Halperin et al 1981). Side effects include gastro-intestinal complications (nausea, emesis, diarrhoea, loose stools, anorexia, abdominal pain, bloating or flatus), impairment in taste and smell (probably due to chelation of zinc), dermatological-mucomembranous complications (pharyngitis, oral ulcers, rash, ecchymosis, pruritis, urticaria, pemphigus, elastosis perforans serpiginosa, skin wrinkling), hypersensitivity reactions (laryngeal oedema, dyspnoea, respiratory distress, fever, chills, arthralgia, weakness, fatigue, myalgia, adenopathy), haematologic abnormalities (leucopenia, agranulocytosis, thrombocytopenia, anaemia, eosinophilia), abnormal liver function tests and renal complication (proteinuria, nephrotic syndrome, glomerulonephritis). In up to 50% of patients, the cessation of D-penicillamine therapy may be required because of these side effects. In some of them, D-penicillamine therapy may be reinstituted by desensitization. This technique entails restarting treatment at a low dose of D-penicillamine of 10–25 mg/day, with a gradual increase in dosage at 3-day intervals until the desired dosage is reached to be achieved over a period of about 1 month.

During long-term therapy, D-penicillamine may cause vitamin B_6 deficiency by binding pyridoxine. Before the appearance of significant symptoms (dizziness, seizures, glossitis, seborrhoeic dermatitis), it may be prudent to provide pyridoxine supplementation (50 mg/day) in patients receiving large doses of D-penicillamine ($>$ 1 g/day) chronically.

When serious side effects preclude D-penicillamine use, the only available recourse currently is to further increase fluid intake, provide more alkali and impose a more rigid methionine restriction.

Alpha-mercaptopropionylglycine (MPG) (Linari et al 1981, Hautmann et al 1977). This drug may serve as a reasonable alternative to D-penicillamine, especially in the setting of toxicity to the latter drug. MPG shares similar chemical properties with D-penicillamine. Because of its higher oxidation–reduction potential, MPG may be more efficient than D-penicillamine in undergoing thiol-disulphide exchange with cystine. The reduction in urinary cystine produced by MPG is equivalent to that obtained during D-penicillamine therapy. Thus, the same comments regarding dosage schedule previously given for D-penicillamine apply to the MPG treatment. Available data from Japan and Europe suggest that MPG is equally as effective as D-penicillamine in inhibiting cystine stone formation.

The major advantage of MPG appears to be its apparent reduced toxicity. A recent review of the literature disclosed 10 reports entailing 120 cystinuric patients undergoing clinical trial with MPG (Pak et al 1986a). Minor gastrointestinal problems occurred in 35 patients, rash in 14, urticaria in 3, pemphigus foliaceus in 1, fever in 7 and nephrotic syndrome in 2 patients. These adverse reactions were generally less common and less serious than those reported in D-penicillamine. Although serious side effects, such as pemphigus and nephrotic syndrome, have also been encountered during MPG therapy, they occurred less frequently. Thus, among 120 patients taking MPG, only 2 apparently had to stop taking the medication because of adverse reactions.

Our own experience is compatible with the above findings (Pak et al 1986a). Since 1980, we have been conducting a multiclinic trial with MPG in the United States in order to assess the therapeutic role of MPG as an alternative to D-penicillamine in the management of cystine nephrolithiasis. The primary objective was to determine the safety and efficacy of MPG in patients with known toxicity to D-penicillamine.

Among 49 patients who took D-penicillamine first and later received MPG, 41 patients (83.7%) developed side effects to D-penicillamine and 37 (76.5%) to MPG. Adverse reactions involved all organ systems. Frequent adverse reactions to D-penicillamine were nausea in 36.7%, emesis in 28.6%, anorexia in 18.4%, rash in 34.7%, proteinuria in 12.2% and fatigue in 16.3%. These reactions were also observed during MPG therapy, but less frequently. Thus, nausea was encountered in 24.5% of patients, emesis in 10.2%, anorexia in 8.2%, rash in 14.3%, proteinuria in 10.2% and fatigue in 14.3%.

Moreover, serious side effects were less common during MPG therapy. Thus, 67.3% of patients required cessation of D-penicillamine treatment, whereas only 30.6% had to stop taking MPG. Among 34 patients who could not tolerate D-penicillamine, 22 could be maintained on MPG.

There were 17 patients without prior history of taking D-penicillamine who were offered MPG for the first time. Eleven patients (64.7%) had adverse reactions while taking MPG. However, many of these reactions were minor or non-specific. Only 1 patient (5.9%) was forced to discontinue MPG treatment because of side effects.

MPG was equally as effective as D-penicillamine in reducing cystine excretion. During long-term treatment with MPG (average dose of 1193 mg/day), urinary cystine was maintained at 350–560 mg/day and urinary saturation of cystine was kept undersaturated. Commensurate with these changes, MPG produced remission of stone formation in 63–71% of patients and reduced individual stone formation rate in 81–94%.

Thus, MPG would seem to have a definite therapeutic role in the management of cystine nephrolithiasis, especially in patients who have developed toxicity to D-penicillamine.

Acetohydroxamic acid for infection stones

If long-standing effective control of infection with urea-splitting organisms can be achieved, new stone formation may be averted and some dissolution of existing stones may be achieved. Unfortunately, such control is difficult to obtain with antibiotic therapy. If there is an existing struvite stone, it is difficult to eradicate completely the infection because the stone often harbours the organisms within its interstices. Even if 'sterilization' of urine can be achieved by antibiotic therapy, reinfection could occur by harboured organisms. For these reasons, surgical removal of struvite stones is usually recommended.

In recent clinical trials, acetohydroxamic acid, a urease inhibitor, has been shown to reduce urinary saturation of struvite and to retard stone formation (Griffith 1978). However, 30% of the patients experienced minor side effects and 15% developed deep venous thrombosis. Additional long-term studies must be done to determine the benefit/risk ratio (Williams et al 1984).

Low urine volume

There is evidence for a strong environmental factor in the pathogenesis of stone formation in this entity. Patients have low urine output (< 1 litre/day) due to disdain for drinking fluids. Some have a history of excessive sweat loss.

Stone formation is generally mild–moderate with an average stone formation of less than one per year. An increased fluid intake sufficient to insure urine output of > 2 litres/day on a consistent basis, brings about a dramatic decline in the urinary saturation of stone-forming salts (by lowering the concentration of stone forming constituents) and may increase the inhibitor activity against calcium oxalate crystallization (probably diluting 'promoter' activity) (Pak et al 1981b). Dramatic improvement in stone disease typically follows after adequate fluid intake.

VALIDATION OF SELECTIVE TREATMENT APPROACH

Most of the above treatment programmes are effective in preventing new stone formation. Unfortunately, most of these studies were conducted prospectively without inclusion of a placebo control group. Thus, non-specific effects of changes in diet and fluid intake and improved patient compliance could have modified the clinical response to treatment. Positive placebo effect on the course of nephrolithiasis is well known (Hosking et al 1983, Preminger et al 1985a).

Although the need for assessment of the placebo effect is clear, randomized trials with inclusion of the placebo control are difficult to conduct, because of unwillingness of patients to participate and the difficulty of disguising some test medications.

Despite a lack of randomization, the following lines of evidence suggest that selective treatments exert a specific favourable effect on the course of stone disease exclusive of 'stone clinic' effects.

Evidence for specific favourable effect of selective treatments

Prevention of stone formation by potassium citrate in patients relapsing on other treatments (Pak et al 1985b, Pak et al 1985a). Fifteen patients continued to form stones (4.9 ± 10.1 stones/year) while maintained on conventional therapy (thiazide, allopurinol or conservative). The addition of potassium citrate significantly reduced the stone formation rate to 0.69 ± 1.98 stones/year, caused remission in 66.7%, and reduced stone formation rate individually in 100% of patients. The stone clinic cannot readily be implicated since the same conservative care of diet and fluid recommendations were provided in the same clinic during relapse on conventional treatment, as well as following addition of potassium citrate.

Recurrence after stopping therapy (Pak 1987c). Ten patients (8 with hypocitraturic calcium oxalate nephrolithiasis, 1 with uric acid lithiasis alone and 1 with uric acid and calcium stones) required cessation of potassium citrate therapy (2 weeks to 16 months). In 4, treatment was resumed. Five of 10 patients formed stones when the treatment was stopped. For the group, the stone formation rate declined from 3.15 ± 4.57 stones/patient/year before treatment (3 years), to total cessation of stone formation during a mean of 7.5 months of potassium citrate treatment ($P < 0.05$). It rose to 10.9 ± 17.4 stones/patient/year upon cessation of therapy (mean of 4.2 months) (not significantly different from the pre-treatment value). On resumption of therapy, stone formation was 0.38 stones/patient/year (over a mean of 20.3 months).

The same conservative care of fluids and diet modification was imposed throughout the follow-up (before, treatment, treatment withdrawal, treatment resumption). Thus, the recurrence of stone formation following cessation of therapy suggests a specific drug effect.

Superiority of potassium citrate over conservative management (Preminger et al 1985a). In order to establish the effect of specific medical treatment from the stone clinic effect, the results of potassium citrate therapy from our long-term clinical trial were compared with those of 11 published conservative or placebo trials. Since patients participating in these conservative/placebo trials had stone disease of mild–moderate severity, 54 patients with stone formation of 1 or less/year were chosen from 89 patients for comparison.

The initial stone formation rate ranged from 0.31 to 0.78 in the conservative/placebo trials, comparable to that of 0.48 to 0.75 in the potassium citrate groups. During conservative/placebo management, stone formation persisted between 0.11 to 0.33. However, new stone formation virtually ceased on potassium citrate therapy (0–0.06). The remission rate was lower during potassium citrate therapy (89–100% vs 43–83%). The group mean stone formation rate declined by 13–84% from the pretreatment value when conservative/placebo management was applied, but it declined much more (89–100%) following potassium citrate treatment.

The above determinants were 'normalized' for all patients participating in conservative/placebo trials and for all patients in the four potassium citrate groups (Table 12.3). The stone formation rate before beginning treatment was comparable between the combined conservative/placebo trials (0.54 stones/patient-year) and the combined groups of patients receiving potassium citrate therapy (0.52 stones/patient-year).

During potassium citrate treatment, only 2 new stones were formed among the 54 patients, yielding a new stone formation rate of 0.02 stones/patient-year. This rate was substantially lower than the value of 0.25 stones/patient-year for the combined conservative/placebo trials.

The remission rate for all groups in the potassium citrate trial was 96%, while only 61% of the conservative/placebo patients remained stone-free. In addition, the decline in the stone formation rate was not as dramatic in the conservative/placebo patients (0.54–0.25 stones/patient-year, 54% decline) as it was in the potassium citrate trial where the stone formation rate dropped 96%, from 0.52 to 0.02 stones/patient-year ($P < 0.001$). Thus, in this group of patients with a mild–moderate severity of stone disease, potassium citrate therapy virtually eliminated new stone formation.

The vastly superior response to potassium citrate suggests that this specific medical treatment exerts an additional favourable effect on the course of stone disease above the stone clinic effect.

For other selective treatment programmes, patients with mild–moderate severity of stone disease also exhibit a superior clinical responsiveness to those participating in placebo or conservative programmes summarized here.

Table 12.3 Comparison of clinical response between combined placebo or conservative programme versus potassium citrate treatment

	Duration of follow-up (years)	Stone formation rate before treatment (no/pt/y)	Stone formation rate on treatment (no/pt/y)	Remission rate (%)	Decline in formation rate (%)
Combined conservative/placebo trials	2.9	0.54	0.25	61	54
Combined potassium citrate treatment	2.1	0.52	0.02^+	96	96

Significant decline in stone formation rate produced by treatment, determined by paired t test, is shown by $^+$ for $P < 0.001$.

Reduced requirement for stone surgery (Pak et al 1985a). In 89 patients participating in a long-term clinical trial at Dallas, an analysis was made of required surgeries for removal of stones. All surgeries were for symptomatic calculi associated with obstruction, intractable bleeding, pain, or fever.

During the 3 years preceding treatment, the 89 patients participating in the study required 61 surgeries for removal of stones (45 'open', 16 'basket'). During an average of 2 years of potassium citrate treatment, only 10 surgeries were required (8 open, 2 basket), all for stones which had been present when the treatment was started. The results provide supporting evidence that potassium citrate treatment inhibited new stone formation.

Dissolution of existing calcium stones (Pak et al 1983). In approximately 40% of patients with existing calcium nephrolithiasis, potassium citrate therapy (> 9 months) caused reduced stone mass, often not accountable by stone passage. A similar apparent dissolution of existing calcium stones has not been reported with placebo or conservative programmes.

Relative ineffectiveness of non-selective therapies. In different groups of patients with absorptive hypercalciuria type I, non-selective treatment with thiazide was less effective in preventing new stone formation than a more selective treatment with sodium cellulose phosphate, as previously enumerated. A similar finding was reported in the same group of patients. When they were first offered sodium cellulose phosphate, 77.8% of them were stone-free. However, when thiazide was given instead, 57.1% had relapse (Pak 1983).

HAZARDS AND EXTRARENAL EFFECTS OF SELECTIVE THERAPY

The theoretical advantage of the selective approach is the assumption that treatments specifically chosen for their physicochemical and physiological effects are less likely to cause side effects and more likely to overcome extrarenal manifestations of the disease process than more randomly chosen programmes. This fact further justifies the adoption of the selective treatment approach.

Side effects of selective therapy

As previously discussed under Selective therapy of nephrolithiasis, even selective treatments are associated with certain hazards. These side effects will be summarized here.

Sodium cellulose phosphate may cause hypomagnesiuria and hyperoxaluria, necessitating magnesium supplementation and dietary oxalate restriction (Pak 1981). Despite a report to the contrary (Backman et al 1979), this drug rarely causes gastrointestinal problems. A report of rheumatic complications is unexpected and unconfirmed. The medication is cumbersome to take, since it is in a powder form and needs to be taken in large amounts.

Thiazide may reduce citrate excretion by producing hypokalaemia (Nicar et al 1984). Hypokalaemia may cause weakness, cramping and cardiac arrhythmia. Hyperuricaemia is invariably found, although clinical gouty arthritis is uncommon. Urinary uric acid may increase during treatment in some patients, suggesting urate overproduction or a reduced gastrointestinal disposal of urate (Pak et al 1978b). Under these circumstances, potassium supplementation and allopurinol may be required. Thiazide may cause hypercalcaemia in patients with an excessive bone resorption. A substantial fraction of patients (approximately 40% in our series) tolerate thiazide poorly, complaining of weakness, lethargy, a general decline in the sense of well-being, or impotence.

Orthophosphate may potentially stimulate parathyroid function and cause soft tissue calcification (Dudley & Blackburn 1970). It may further exaggerate hyperparathyroidism and cause deterioration of renal function in patients with renal failure. Most patients experience softer bowel movements, though frank diarrhoea is uncommon. These gastrointestinal symptoms often become less severe with continued therapy.

Allopurinol is surprisingly well tolerated. Most patients do not experience any adverse symptoms when they take the medication. In our series, less than 1% of the patients developed a rash during treatment. Abnormalities in peripheral blood counts or in liver function were equally uncommon.

Potassium citrate is available as a slow-release tablet form or as a liquid preparation. We recommend the liquid preparation (three to four divided doses each day) in chronic diarrhoeal states and tablet preparation in other conditions. The tablet preparation should be given with meals (usually with breakfast and dinner) in order to reduce gastrointestinal side effects. Minor gastrointestinal complaints (abdominal distress, diarrhoea, nausea, indigestion, distaste, burning) were common with the liquid preparation (27.2%), they were less frequently encountered with the solid preparation (9.3%) (Pak et al 1985a). None of the patients compained of melaena. Stool for occult blood (by Hemoccult test) was negative in all 59 patients taking Urocit, in whom the test was performed.

Among 89 patients participating in long-term trial at Dallas (Pak et al 1985a), no significant change occurred in venous blood reticulocyte count, serum calcium, or creatinine clearance. There was a small increase in venous blood haematocrit, serum potassium and carbon dioxide during some treatment periods; however, these values remained within normal limits.

There were no significant changes in other blood cell indices, serum iron, phosphorus, sodium, chloride, albumin, total protein, bilirubin, lactic dehydrogenase, glutamate-oxaloacetate transaminase or in alkaline phosphatase. Potassium citrate should not be given to patients with active peptic ulcer disease, significant renal impairment or any hyperkalaemic state.

Adverse reactions to D-penicillamine are common and sometimes serious, including oral ulcers, urticaria, pemphigus, laryngeal oedema, fever, myalgia, leucopenia, agranulocytosis and nephrotic syndrome. Although complications may also occur with MPG, they are apparently less common and severe (Pak 1986a). Acetohydroxamic acid may cause haemolytic anaemia and deep vein thrombosis.

Side effects of non-selective therapy

The above hazards of selective treatments are those attributable to the intrinsic properties of the drugs themselves. Additional side effects could develop from inappropriate use of drugs.

Treatment of renal hypercalciuria with sodium cellulose phosphate may exaggerate secondary hyperparathyroidism and aggravate or produce bone disease. The use of this calcium binding agent in patients with normal calcium absorption could cause a negative calcium balance. Similarly, a limited calcium diet in patients other than those with high calcium absorption may produce a calcium deficient state.

The sequelae of non-selective use of thiazide in absorptive hypercalciuria type I were previously enumerated. They include transient retention of calcium in the skeleton (Pak et al 1982) and eventual loss of the hypocalciuric response (Preminger & Pak 1987). Thiazide may cause hypercalcaemia in patients with resorptive hypercalciuria.

Parathyroidectomy is not 'curative' for renal hypercalciuria. There may be recurrence of renal hypercalciuria and nephrolithiasis after surgery.

Orthophosphate therapy for normophosphataemic absorptive hypercalciuria may cause calcium retention, since high intestinal calcium absorption is maintained despite a reduction in urinary calcium. As noted, there are reports of parathyroid stimulation and soft tissue calcification during orthophosphate use (Dudley & Blackburn 1970).

There is no evidence that the use of potassium citrate in normocitraturic states at customary dosages ($<$ 80 mEq/day) would be harmful. However, if this drug is used in the presence of urinary tract infection, it may aggravate the infection and promote calcium phosphate precipitation.

We would consider substitution of potassium citrate by sodium alkali to be non-selective. When sodium alkali is given it may increase urinary calcium and sodium (Sakhaee et al 1983). Thus urinary saturation of calcium salts may increase and urate-induced crystallization of calcium salts may be promoted. These effects may override the citraturic response of the alkali therapy. Thus, complication of calcium stones may occur during sodium alkali therapy. In five patients with documented uric acid lithiasis studied by us recently (Pak et al 1986b), treatment with sodium bicarbonate or sodium citrate caused calcium stones (calcium oxalate, calcium phosphate, or both) in all five. When potassium alkali was provided, no new stones were formed.

These potential complications of non-selective treatments attest to the value of the selective approach.

Extrarenal manifestations

Even if conservative treatments inhibit stone formation, additional therapies may be indicated for the prevention of extrarenal complications. Nephrolithiasis should be considered as potentially representing a multisystem disease in which stone formation is only one manifestation. Selective treatment of nephrolithiasis may also correct attendant non-renal complications (Table 12.4).

In renal hypercalciuria there may be skeletal involvement, as indicated by a reduced bone density noted on photon absorptiometry (Lawoyin et al 1979). Selective treatment with thiazide may avert this complication by restoring normal parathyroid function, as shown by stable bone density during long-term follow-up (Pak et al 1982).

Primary hyperparathyroidism is manifested clinically by peptic ulcer disease and bone disease, as well as by nephrolithiasis. Parathyroidectomy typically averts all three manifestations.

Although controversial, there is some evidence that bone may be affected adversely in patients with renal phosphate leak because of hypophosphataemia (Bordier et al 1977). Orthophosphate therapy may retard this development.

Various cardiac and musculoskeletal side effects (Hollifield 1986) may accompany the hypokalaemia resulting from renal tubular acidosis, chronic diarrhoeal states and thiazide-induced hypocitraturia. Potassium citrate may correct this complication unless there is severe chloride deficiency.

In renal tubular acidosis (distal) there is subnormal intestinal calcium absorption and hypercalciuria. Bone disease may develop. Potassium citrate therapy improves calcium balance by increasing intestinal calcium absorption and reducing calcium excretion, and thus averts bone loss (Preminger et al 1987).

These examples, showing the ability of selective treatment to overcome non-renal complications, further justify the adoption of the selective treatment approach.

Table 12.4 Effect of selective treatments on non-renal manifestations

Condition	Non-renal complication	Corrective selective therapy
Renal hypercalciuria	Bone disease	Thiazide
Primary hyperparathyroidism	Bone disease Peptic ulcer	Parathyroidectomy
Renal phosphate leak	Bone disease Myopathy	Orthophosphate
Distal renal tubular acidosis Chronic diarrhoea Thiazide therapy	Hypokalaemia	Potassium citrate
Distal renal tubular acidosis	Bone disease	Potassium citrate

SUMMARY

From the preceding discussion, it should be clear that the adoption of a selective treatment programme can be amply justified.

First, selective treatments are highly effective in preventing new stone formation. A remission of stone disease could be achieved in more than 80% of patients overall, and a reduction in individual stone formation rate in greater than 90% of patients. In patients with mild–moderate severity of stone disease, a virtual total of stone disease (remission > 95%) can be achieved. The need for stone removal may be dramatically reduced by an effective prophylactic programme. There is some evidence that certain stones (even calcareous types) may undergo dissolution in vivo with appropriate therapy.

Second, selective treatments avert certain side effects which could be caused by non-selective treatments.

Third, selective treatments are capable of overcoming non-renal manifestations as well as preventing new stone formation.

Despite these advantages, it is clear that the selective medical treatment approach *cannot* provide total control of stone disease. Stone disease generally presents with a 'surgical' problem related to an already formed stone before medical diagnosis and selective treatment may be applied. Some patients, albeit a minority, are recalcitrant to medical therapy no matter how heroic. A satisfactory response requires continued dedicated compliance by the patients to the recommended treatment programme, and a commitment of the physician to provide long-term follow-up and care. There is no cure, only prophylaxis.

It is therefore apparent that the control of stone disease requires application of both 'surgical' and medical approaches.

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